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ORIGINAL ARTICLES.

Outline of the Geological History of the N'Changa District, Northern Rhodesia.

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Introduction.

THE geological succession of the rocks of the N'Changa District is so typical of that of the Northern Rhodesia Copper Belt as a whole, and indeed of much of the Colony of Northern Rhodesia, that it is felt that a summary of the sequence of events which together make up the geological history of the district may serve as a contribution to the geological literature of the general Northern Rhodesian field. For a fuller account of the details of the petrography and mineragraphy of the rocks and ores of the N'Changa District reference should be made to Bancroft and Pelletier (1929), and Jackson (1932).

Any account of the historical geology of this portion of Northern Rhodesia must necessarily be derived almost entirely from petrological and structural evidence. Fossiliferous horizons are absent, the younger formations such as the Permian beds found elsewhere in Northern Rhodesia having long since been removed by erosion. The rocks of the district have been metamorphosed both regionally and by the action of intrusive rocks; wide areas are, in many localities, practically devoid of outcrops, and in the older members the geological record is by no means clear. Nevertheless, sufficient remains to indicate the sequence of the principal geological events. For data concerning Post-Kundelungu sedimentation the writer has availed himself freely of the results of other geological workers in the neighbouring districts.

The following table gives a chronological outline of the geological history, a more detailed discussion of which follows :—

N'CHANGA DISTRICT, NORTHERN RHODESIA.

Tabular Statement of Principal Geological Events.

Recent.	Rejuvenation of erosion cycle, with concurrent deposition of alluvium, and formation of laterites.
Tertiary.	Formation of desert detritus of Kalahari System.
Cretaceous.	Erosion and peneplanation.
Jurassic.	Erosion (?).
Upper Carboniferous to Triassic.	Sedimentation; deposition of Karroo System (absent in N'Changa District owing to subsequent peneplanation).
Early Palaeozoic or Pre-Cambrian.	Erosion.
	Injection of auto-scapolitized norites and gabbros, mainly in the form of sills.
	Orogenic movements and developments of present synclinal fold-system; intrusion of Younger Grey "Granites" and N'Changa Younger Red Granite, with accompanying copper mineralization.
	Deposition of Kundelungu Series.
	Sedimentation; deposition of Bwana M'Kubwa Series.
Archaean (?).	Erosion.
	Orogenic movements; intrusion of M'Kushi Granite Gneiss, Muliashi Porphyritic Gneiss, and N'Changa Older Red Granite.
	Sedimentation; deposition of Muva Series.
	Erosion (?).
	Sedimentation; deposition of Basement Schist Series.

PRE-BWANA M'KUBWA SEDIMENTATION.

(*a*) *Basement Schist Series.*—Within the district and, so far as is known, over the greater part of Northern Rhodesia, the earliest record was one of sedimentation when an enormous thickness of sandy shales and shaly sandstones were laid down in an ancient geosyncline—later to be dynamo-thermally metamorphosed into a wide variety of quartz-mica and quartz-chlorite schists, now forming the Basement Schist Series.

The presence of obscure cross-bedding structures in these rocks at different localities in the Kafue Valley and the characteristically sandy nature of the original sedimentation over widely distributed areas suggests continental deposition under shallow-water conditions in a large basin of sedimentation. The origin of these ancient sediments is not known. Volcanic types, so abundant in rocks of similar age in Southern Rhodesia and elsewhere, are entirely absent.

(*b*) *Muva Series.*—Following the deposition of the rocks now forming the Basement Schist Series, there were deposited great thicknesses of sediments, finely argillaceous in their lower members, but becoming strikingly arenaceous towards the top. These are now represented respectively by the Muva Schists and the Muva Quartzite.

No unconformity has been observed between the Muva and the Basement Schist Series, for they have never been found in contact with one another. The well-bedded character of the Muva Quartzite, however, is in such sharp contrast to the nearly complete obliteration of bedding in the Basement Schists, that it is almost certain that a long period of time, accompanied by regional deformation, must have elapsed between the deposition of these two Series.

The great thickness of limestones and dolomites of the Broken Hill Series of Bancroft and Pelletier, stated to be contemporaneous in age with the Muva Series, appears to be absent in the N'Changa and neighbouring districts. This absence may indicate sedimentation of a more arenaceous type, and under shallower water conditions, than in the neighbourhood of Broken Hill.

The relatively sandy character and the rapid alternation of rock types of the upper Muva beds may have been governed by the early stages of orogeny which were to follow.

EARLY OROGENIC MOVEMENTS AND GRANITIC INTRUSIONS.

Towards the close of Muva sedimentation a widespread and prolonged period of mountain-building took place. The entire Pre-Bwana M'Kubwa geosyncline was uplifted and thrown into a system of parallel anticlines having a general north-north-west trend. Accompanying this orogeny were large-scale intrusions of diverse granitic types. Stocks of the Muliashi Porphyritic Granite-Gneiss invaded the northern margin of the district, while portions of the M'Kushi Granite-Gneiss complex were probably intruded at this period, followed, possibly slightly later, by the localized Older Red Granite of the N'Changa composite stock.

Crustal deformation continued after batholithic invasion had ceased and the granitic rocks themselves were strained and crushed, rendering them, according to their composition, either gneissoid or granulitic.

SUBSIDENCE AND BWANA M'KUBWA SEDIMENTATION.

The great epoch of Pre-Bwana M'Kubwa orogeny and batholithic invasion was succeeded by one of prolonged denudation and unroofing of the granitic batholiths. This was followed by a gradual and widespread subsidence of much of the land-mass, and, into basins of sedimentation thus formed, the basal conglomerates and arkosic sandstones of the Bwana M'Kubwa Series were deposited. The period of erosion which accompanied the uplift and subsidence must have been of great duration, for, not only were the roof-rocks of the granitic mass removed, but erosion had carved sufficiently deeply into the batholithic cores themselves to provide abundant granitic pebbles for the basal conglomerate of the Bwana M'Kubwa Series.

These rocks were deposited along basins which must have followed closely the older tectonic lines of the terrain. This is indicated by the manner in which the strike of the Bwana M'Kubwa sediments roughly parallels that of the Muva Series, although the dip of the Bwana M'Kubwa is considerably flatter.

The earliest Bwana M'Kubwa beds are highly arkosic, coarse, and poorly stratified. The clastic constituents of the arkose are angular and relatively fresh; it is probable that they were transported for only short distances prior to deposition, and were derived from a land-mass of high relief and rapid erosion. The arkosic portion of the great thickness of basal material was probably derived from the products of erosion of portions of the older granitic batholiths, while the more quartzose portions were obtained partly from the same source and partly from the erosion of the paraschists and quartzites of the Basement Schist and Muva Series. Locally, great thicknesses of boulder and gravel beds were deposited, the appearance of which suggests accumulation under storm conditions along deeply embayed portions of the ancient coast-line. Possibly, the relative thickness of these isolated boulder beds may indicate to some extent the depth of embayment at any one locality. Upon these boulder deposits, or, where absent, directly upon the eroded shore-line itself, were deposited several thousands of feet of arkosic and argillaceous sandstones, with narrow intercalated conglomerate beds. Rapid currents prevailed at the time of deposition, as is indicated by the abundance and strength of cross-bedding at many horizons. These beds, since metamorphosed, now represent the Quartzitic Arkoses and the conglomeratic Orange Schistose Grits of the Lower Bwana M'Kubwa Series.

These earlier deposits of the Series, then, were deposited under shallow-water conditions in a slowly sinking geosyncline. Later as subsidence continued the area of deposition widened and there were laid down finer sediments of more argillaceous and calcareous composition. Fluctuations in this subsidence are suggested by occasional interstratified beds of coarser material. These argillaceous and calcareous sediments constitute the Middle Bwana M'Kubwa, together with the upper portion of the Lower Bwana M'Kubwa Series. As subsidence continued, the deposits became more and more calcareous, and are now represented by the Chingola Dolomite and associated beds. Some doubt exists regarding the conditions under which these carbonate-rich sediments were formed; possibly they were deposited at considerable depths, but the repeated appearance of coarser siliceous facies at different horizons suggests a shallower basin of sedimentation. It is possible that these beds were formed at relatively shallow depth near the mouths of large rivers which drained a region reduced by long-sustained denudation to a plain of low relief where chemical solution was more active than mechanical erosion.

With the deposition of the Upper Bwana M'Kubwa Series (Mwashia Series) the sediments became coarser and less calcareous than those of the Middle Bwana M'Kubwa and showed rapid alternation in type and grade, being mainly thin-bedded and banded. Arkosic rocks were laid down near the top, but the Series was predominantly argillaceous. At some time during this period impure thin-bedded sandstones were deposited, later to be altered by contact-metamorphism, induced by the Basic Intrusive sills, into the Phosphatic-Quartz-Magnetite-Schists.

KUNDELUNGU SEDIMENTATION.

At the close of Upper Bwana M'Kubwa sedimentation the character of the deposits changed abruptly with the deposition of the basal conglomerates of the Kundelungu Series. Probably no great interval of time elapsed between the deposition of these two Series, although this remains unproved. The Kundelungu epoch opened with the deposition of several hundred feet in thickness of coarse conglomerates with an unstratified argillaceous, graphitic matrix. These basal rocks outcrop strongly on the Lufubu River towards the N'Kana Concession boundary. The conglomerates were succeeded by a great thickness of dolomitic phyllites and dolomites, grading upwards into beds of more arkosic and arenaceous character—the Plateau Arkoses. A narrow but persistent pebble bed known in the Katanga as the "Petit Conglomérat" was deposited near the middle of this Series. Neither the Petit Conglomérat nor the Plateau Arkoses, however, appear to be represented within the N'Changa district. The biotite-spangled Lufwanyama Schists and Granulites of the Lufwanyama and Katembula Rivers are considered by the writer to have been laid down as an impure calcareous phase during earlier Kundelungu sedimentation.

Subsidence continued rapidly and the basins of sedimentation widened, the basal Kundelungu beds transgressing directly in many places upon the ancient Basement Schist land-mass.

Some of the characters of the Kundelungu basal conglomerates suggest a glacial origin. The entire lack of stratification at outcrop and the form of the quartz flakes of the matrix, as seen in thin section under the microscope, are suggestive in this particular.

Gray [1] has put forward the suggestion that these beds may represent fluvio-glacial deposits rather than tillites. It is not known whether this possible glaciation was confined merely to the time occupied by the deposition of the conglomerates, or whether it covered a much greater period. Possibly it may have been related to the early stages of the great Post-Kundelungu period of elevation and mountain-building (with concomitant batholithic invasion) which followed.

MOUNTAIN-BUILDING: INTRUSION OF YOUNGER GRANITIC ROCKS AND ATTENDANT MINERALIZATION.

Following the deposition of the Kundelungu a period of widespread and powerful crustal compression threw the sediments into great folds having a north-north-west trend, remnants of which now form the roughly parallel synclines of the Northern Rhodesian Copper Belt. In the Katanga, to the north, orogeny was still more intense, the folds being strongly overturned, with the development of nappe structures.

Accompanying or closely following these crustal movements granitic rocks were intruded on a batholithic scale. The earlier of these intrusives comprise the biotite-granodiorites, adamellites, and granites grouped under the general term of Younger Grey "Granites". These were followed by the intrusion of the N'Changa Younger Red Granite on the site of an older red granite of similar composition. The Grey "Granites" occasionally show gneissose structures (absent in the Red Granite), possibly indicating intrusion while this period of orogeny was still operating.

The final pneumatolytic phases of these granitic masses was marked by the injection of dykes and veins of aplite, pegmatite, and quartz; by much granitization of the basal members of the Bwana M'Kubwa Series, particularly in the neighbourhood of the Lufwanyama and Katembula Rivers; and large scale mineralization along favourable horizons of the Bwana M'Kubwa Series by disseminated sulphides, principally of copper and iron. At this stage, mountain-building had practically ceased, and the sulphide particles were deposited in the fracture-cleavage previously impressed upon certain of the beds by dynamo-thermal metamorphism during their deformation.

The intrusion of these younger granites subsequent to the main period of folding has, in many localities, broken the regularity of folding by up-doming portions of the synclines. An example of this structure is well displayed in the Katembula-Lufwanyama Dome.

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[1] Anton Gray, *An Outline of the Geology and Ore-Deposits of the N'Kana Concession*, London, 1929, 22.

INJECTION OF SCAPOLITIC BASIC SILLS.

Subsequent to the deposition of the Kundelungu Series, and probably later than any of the granitic invasions, occurred a large-scale intrusion into beds of the Bwana M'Kubwa Series of sill-like bodies of gabbro and norite. The late pneumatolytic stage was marked by a phase of auto-scapolitization by magmatic residues rich in sodium and chlorine. This late-phase was accompanied by some scapolitization of shaly wall-rocks, and by albitization of the dolomitic breccia at the top of the Lower Bwana M'Kubwa Series.

This period of sill invasion may have taken place during a period of structural " relaxation ", after the mountain-building forces (and granitic invasion) had ceased. Possibly this phase of basic sill injection was accompanied by outpouring of surface flows, long since removed by the deep erosion of this portion of the Central African Plateau ; it was probably related to the period of basic intrusives which gave rise to the Great Dyke of Southern Rhodesia.

PERMIAN SEDIMENTATION.

Little is known concerning the events which took place during the long period which elapsed between the Kundelungu epoch and the Permian. The length of this period is indicated principally by the angular unconformity at the base of the Permian, and by the rich fossil flora in the Permian beds in contrast to the total absence of any fossil remains in the Kundelungu. Probably this interval represents the greater part, at least, of the Palaeozoic, during which lengthy period uplift, mountain-building, and batholithic invasion took place.

Owing to deep erosion and the absence of Rift Valley faulting within the N'Changa and adjacent districts, all traces of Permian sedimentation are lacking, and the general geology of Northern Rhodesia, as a whole, must be drawn upon to furnish evidence in this connection. Bancroft and Pelletier[1] have described Permian beds of the Karroo System of South Africa, from the Loangwa, Lukushashi, and Luano Valleys—branches of the Lake Nyassa Rift Valley. These beds consist of several hundred feet of conglomerates, sandstones, shales, and some limestones, carrying plant-remains, including *Glossopteris* and silicified wood.

South of the Kafue River to the west of the Livingstone–Broken Hill railway line, and on the lower reaches of the Lunga River, the plateau is underlain by gently-dipping sandstones and shales with thin beds of argillaceous limestone, possibly of Rhaetic age. These, together with the Batoka Basalts of the Livingstone area, the outcrops of which form the Victoria Falls and Gorge, constitute the principal remnants of a great succession of sedimentary and volcanic rocks of the Karroo system which probably covered the greater part of Northern and Southern Rhodesia, as well as extensive areas in South and East Africa.[1]

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[1] J. A. Bancroft and R. A. Pelletier, " Notes on the General Geology of Northern Rhodesia " : *Guide Book, Internat. Geol. Cong. Session, S. Africa,* 1929, 11–12.

CRETACEOUS (?) PENEPLANATION.

Following the close of Karroo sedimentation in late Triassic time, the land-surface was elevated and subsequently peneplained. This peneplanation of the Central African Plateau is believed to have taken place during the Cretaceous, and its effects largely control the present topography.

RECENT DESERT CONDITIONS.

Relatively little remains of the geological record from the Karroo to Recent time. The soil, however, contains over wide areas and at an average depth of from fifteen to twenty feet a persistent layer of quartz pebbles, many of which are distinctly faceted and somewhat resemble wind-blown pebbles typical of those found in modern deserts. The presence of these widely distributed pebbles lying within unconsolidated material, suggests that until relatively recent times, this well watered and forested part of Northern Rhodesia was an arid desert; possibly a former extension of the modern Kalahari Desert.

PRESENT GEOLOGICAL TIMES.

Following these comparatively arid conditions, the climate gradually changed to its present condition of abundant rainfall during the summer months. The country became thickly forested by an upland flora; humic acid attacked all but the more resistant rocks, burying them beneath a thick mantle of residual soil. With increased rainfall, lateritization of the soil set in, particularly over areas underlain by the more ferruginous rocks. The rivers and streams commenced to dissect the surface of the peneplain, and the present very youthful stage of the new physiographic cycle was inaugurated.

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[1] A. J. C. Molyneux, "The Karroo System in Northern Rhodesia": *Q.J.G.S.*, lxv, 1909, 409–439.

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The Raised Beaches and Other Terraces of the Channel Islands.

By A. E. Mourant, M.A., D.Phil.

RAISED beaches and terraces generally are a common feature of the coast scenery of the Channel Islands. An attempt is made here to systematize them and to correlate them with other evidence of old base-levels and, very tentatively, with similar terraces elsewhere. The scattered descriptions in the literature have been brought together and detailed field-work, including measurements, has been carried out in Jersey. The main object of the paper is to give an ordered presentation of the facts as a contribution towards the attempts, now being actively pursued, to co-ordinate the drift deposits of north-western Europe. Any excursion beyond the bare facts is made chiefly in the interests of coherence, and many possible and even obvious theoretical conclusions have been omitted. The history of the subject shows that this does not matter as readers will be able to supply immediately all the ideas that have occurred to the writer and many others besides.

Previous Work.

Collenette[1] has measured the levels of a great many Guernsey raised beaches and finds that they nearly all fall into two clear groups at about 25 and 53 feet respectively above O.D.[2] There is perhaps a third group at about 70 feet. Caves, perhaps of marine origin, occur in igneous or metamorphic rock (not limestone) at 125 feet (Les Thielles) and 270 feet (Corbière). The 50 ft. beach is said to overlie the 25 ft. with a layer of head in between in caves at Moulin Huet and Icart. An ancient submerged beach at about modern sea-level occurs in several places.

According to De la Mare[3] there are three examples of high raised beaches in Alderney, the heights above mean sea-level being respectively 77–80, 58, and 45–50 feet. The pebbles in the highest beach are mixed with angular rubble and may be *remanié*. The writer has seen the higher two of these. The 58 ft. one contains abundant erratic flint pebbles. De la Mare also mentions a beach at 23 to 26 feet as being common in Alderney.

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[1] A. Collenette, "The Pleistocene Period in Guernsey": *Trans. Guernsey Soc. Nat. Sci.*, vii, 1916, 337–408.

[2] Ordnance Datum (mean sea-level). Except where the contrary is stated the height given for a raised beach is the mean height of the deposit. Some confusion with regard to levels has occurred in the past owing to the large range of the tides (30 feet in Guernsey, 40 feet in Jersey), which brings the 25 ft. beach very near the modern high-water mark.

[3] G. De la Mare, "Annual Report of Geol. Committee": *Trans. Guernsey Soc. Nat. Sci.*, iv, 1900, 12–14.

In a cave near Vermandée, Sark, Cachemaille [1] speaks of a heap of large pebbles "fully 50 feet above the level of the sea".

Marett [2] has compiled a very full list of the Jersey raised beaches. The heights given are admittedly only approximate but they nearly all fall into two groups, 25–30 and 60–70 feet, respectively, above O.D. Full references to previous literature are included, and the relations of the beaches to one another and to other Pleistocene formations are discussed. These relations are considered below.

THE SUBMERGED BEACH.

At a number of points on the Jersey foreshore a cemented pebble deposit, probably corresponding to the Guernsey submerged beach, crops out in the midst of the modern beach. Its average height is roughly 10 feet above O.D. At Bonne Nuit Bay and St. Catherine's Bay the deposit is a hard ferruginous conglomerate. In St. Aubin's Bay, about 200 yards north of Noirmont Point, less iron is present and the very rotten state of the granite boulders shows that the formation is ancient; erratic flints are abundant. The low-level beach at Seymour Tower, described by Duprey,[3] is probably part of the same formation. None of the exposures gives any stratigraphical clue to the age of the beach.

THE 25 FT. RAISED BEACH.

The most clearly defined and best-preserved raised beach in the islands is that which occurs at innumerable points a short distance above high-water mark. The sea which laid it down is clearly responsible for cutting many of the existing coastal cliffs. Its mean height in Guernsey is given by Collenette [4] as 25·5 feet, but he omits from his calculation two levels above 30 feet which ought almost certainly to be included. The recalculated mean level is 26·7 feet above O.D. The mean of all measured heights in Jersey is 26·6 feet.

In Jersey most of the exposures are very near the average level, but the denuded platform is often seen sloping down to about 20 feet while in a few caves on the north coast the maximum height reaches about 40 feet. At Grand Becquet a large cave is floored by an expanse of boulders sloping gently from 20 to 45 feet above O.D. Near by, at Le Cané de la Rivière, a mass of rounded boulders in an upper storey to a modern cave is, to the writer's eye, perfectly continuous from 24 to 40 feet above O.D., and is succeeded by subangular blocks. Marett[1] considers that the upper or 50 ft. raised beach is here superimposed on the 25 ft.

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[1] J. L. V. Cachemaille, *Descriptive Sketch of the Island of Sark*, Guernsey, 1875.

[2] R. R. Marett, "Pleistocene Man in Jersey": *Archaeologia*, lxii, 1911, 449–480.

[3] E. Duprey, "Note sur un ancien Rivage submergé dans la Baie de Grouville": *Bull. Soc. Jersiaise*, ix, 1919, 124–5.

[4] A. Collenette, loc. cit.

One of the best exposures of the 25 ft. beach occurs on the south-east coast of Jethou, where it was first reported by Hill.[2] Collenette[3] also mentions the beach as occurring in Herm and Brecqhou.

Two fossiliferous beaches in Jersey at about this level have been described. The better developed and the only one now visible is that which partly filled the end of the stalactite cave at Belle Hougue Point. In addition to a fauna differing little from that on the modern beach it contained, according to Newton,[3] *Astralium rugosum*, the northern limit of which is now south-western France. Andrews[4] also mentions bones of deer, specifically unidentifiable but probably Pliocene. These appear to have lain on or near the top of the beach[5] and it is probable that the mammals occupied the cave after the sea had left it. There is no good evidence of human occupation.

A lithologically similar deposit is found in another cave on the western side of Belle Hougue Point, extending from 24 to 32 feet above O.D. It differs in being almost completely decalcified so that only a few minute shell fragments are present and in being directly overlain by about 10 feet of head.

Danby[6] mentions a fossiliferous raised beach on the north side of the Hermitage Rock, St. Helier. It was obliterated by the harbour works before he had an opportunity to study it closely. He merely mentions that the shells were a modern assemblage. It is evident from his description and the present state of the site that the level was roughly 25 feet above O.D.

Derrick[7] says that shells occur in gravel, apparently near the same level, on the wall of a cave at Château d'Icart in Guernsey.

As pointed out by Prestwich,[8] the 25 ft. beach of Jersey and Guernsey is commonly covered by head, and the beaches themselves contain flint erratics. The writer has also found foreign quartzite in them in Jersey. The beach almost invariably overlies solid rock ; occasionally it is disturbed and mixed with the head. At Portelet Bay, Jersey, however, it overlies brickearth and head. The exposures have been carefully described and figured by Lawson,[9] but in view of their importance they have been re-examined closely by the writer. Immediately west of the footpath leading down from Portelet Farm the cliff shows the following section :—

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[1] R. R. Marett, loc. cit.

[2] E. Hill, "The Rocks of Sark, Herm, and Jethou": *Quart. Journ. Geol. Soc.*, xliii, 1887, 322.

[3] C. W. Andrews, quoting R. B. Newton, "Report of Archaeological Section": *Bull. Soc. Jersiaise*, ix, 1919, 108.

[4] C. W. Andrews, loc. cit.

[5] H. Morin, "Grotte de la Belle Hougue, Trinity": *Bull. Soc. Jersiaise*, ix, 1919, 109–112.

[6] T. W. Danby, "Elevation and Subsidence of Land in Jersey": GEOL. MAG., 1876, 143.

[7] G. Derrick, *Trans. Guernsey Soc. Nat. Sci.*, i, 78–82.

[8] J. Prestwich, "On the Evidence for a Submergence of Western Europe" . . . etc.: *Phil. Trans.*, clxxxiv, 1893, 903–984.

[9] H. S. Lawson, "Notes on the Low Level Raised Beach at Portelet Bay": *Bull. Soc. Jersiaise*, vii, 1914, 456–7.

		Ft.	in.
5.	Yellow Clay (loess) . . .	10	0
4.	Reddish brown stony clay (head)	10	0
3.	Reddish brown sand . . .	5	0
2.	Large well-rounded pebbles . .	1	6
1.	Reddish brown clay . . .	2	0

The base of the section is hidden by the modern beach at a height of about 23 feet above O.D. The lowest clay is practically stoneless but rather deeply coloured for loess. It shows horizontal banding which may be due either to successive deposition or to solifluction. It is evidently loess or stoneless head. The junction with the pebble-bed is clearly marked and the matrix of the latter is sand quite distinct from the clay below but very similar to the sand above which grades upward into the head. The sand between and above the stones is a normal raised beach feature. This and the regularity and sharp base of the pebble bed make it unlikely that the bed has been much disturbed since it was laid down.

For about 10 yards east of the place described the section is obscured. Beyond this break the pebble-bed is again seen but at a level about 2 feet higher and resting on a thick deposit of head. The pebbles themselves still show little or no sign of disturbance. In the north-east corner of the bay, however, rounded and angular stones are found mixed together in the head.

Since both head and loess are generally considered to have been formed while northern Europe was glaciated these sections strongly suggest that this beach deposit, and the 25 ft. raised beach generally, is an interglacial formation. It is possible, however, that the pebbles rode, by solifluction, over a later-formed clay.

There is a clear case for correlation with the sub-head low-level raised beach of the south of the British Isles. Wright [1] shows that the erratic pebbles in the latter were probably brought by floating ice. This agrees with the occurrence in a beach at about the same level near Le Hâvre in Normandy of the arctic *Buccinum groenlandicum.*[2] Wright considers that the beach in the British Isles was absolutely, though immediately, pre-glacial.

The Belle Hougue beach agrees well in morphology with the other fragments of the 25 ft. beach in the islands but the warm fauna seems to dissociate it from examples in other parts of the English Channel and we cannot at present entirely disregard the possibility that it may be Pliocene as the fragmentary mammalian remains suggest.

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[1] W. B. Wright, *The Quaternary Ice Age*, London, 1914, 93–102.

[2] C. Depéret, " Essai de Coordination Chronologique Générale des Temps Quaternaires " : *Comptes Rendus Acad. Sci.*, Paris, clxvii, 1918, 418–422.

THE 60 FT. RAISED BEACH.

No raised beaches are known in Jersey with mean heights between 35 and 50 feet above O.D., but there is a clearly marked group at about 60 feet. The mean of eight fairly accurate measurements of height, six of them by the writer, is 60·1 feet. The mean height of three high-level beaches in Alderney [1] is 61·3 feet. On the other hand Collenette [2] considers that the mean height of the main high-level group of Guernsey beaches is 53·4 feet. Actually he separates two groups, round about 55 and 70 feet respectively. The mean of all the measurements is 62·2 feet,[3] in good agreement with Jersey and Alderney. The apparent gap at about 60 feet is probably an accident due to the small number of observations since no such gap appears in Jersey. It seems best to regard all the beaches at about 60 feet as contemporaneous in the absence of convincing arguments, statistical or stratigraphical, for separating them.

The granite pebbles in the 60 ft. beach are generally more deeply weathered than in the 25 ft. beach, but this may be due to the absence of that thorough sealing with head that the lower beach has frequently undergone. The 60 ft. deposit in Jersey is nevertheless often covered with head. In two cases, at Le Pinacle and at Belle Hougue Point, the groove carved out by the beach is clearly marked in the upper part of a cave of which the bottom is still reached by the sea, but the groove and the fissure above and below it are filled with head. At Belle Hougue Point the 25 ft. beach is actually present in the same cave while at Le Pinacle it occurs in a cave connected by a tunnel to the one with the 60 ft. groove. The simplest way of explaining these occurrences is by supposing the sea which laid down the 25 ft. beach to have breached the floor of the 60 ft. cave. When the sea had retired the cave was largely filled with head, most of which has been removed by the sea acting at its present level.

The exposures of the 60 ft. raised beach are usually very small, and if erratic pebbles are present but scarce they may easily be missed, but the one known case of flints in such a beach, in Alderney, shows that floating ice had probably already made its appearance in the English Channel.

The most definite evidence for the age of any raised beach in the islands is that adduced by Marett,[4] who pointed out that the Mousterian sites of La Cotte à la Chèvre and La Cotte de St. Brelade, Jersey, are both caves belonging to the 60 ft. raised beach. In the former the sea-gravel is separated only by 6 inches of cave-earth from the Early Mousterian implementiferous bed. In the latter the level of the rather later Mousterian occupation is underlain by several feet of deposits, mostly head. Beach-gravel has not been discovered, but the sea-worn platform is probably some 6 feet below the Mousterian floor. The 60 ft. raised beach was thus laid down before—probably just before—Early Mousterian times.

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[1] G. De la Mare, loc. cit.

[2] A. Collenette, loc. cit.

[3] Giving his "mean of four estimated" half weight, i.e. taking it as only two observations. Giving this mean full weight would bring the general mean to 63·5 feet.

[4] R. R. Marett, loc. cit.

THE 120 FT. RAISED BEACH.

The only definite raised beaches in the islands more than 80 feet above O.D. are those at South Hill and near St. Clement's Church, Jersey. On the top of South Hill is a fairly well cemented beach consisting of large boulders and pebbles, mostly of granite similar to that composing the hill. The height of the deposit, according to a section given by Naish,[1] is from 122 to 138 feet above O.D. On the east side of the quarry which lies east of the main hill a raised beach has been found between 103 and 114 feet. It consists of small pebbles and sand and is quite different in appearance from that at the higher level; it looks younger. We are, however, hardly justified, without further evidence, in separating these beaches. The rock underlying the eastern exposure is disturbed so as almost to resemble head. That the disturbance was produced before the beach was laid down is shown by the state of some large blocks of granite which are well rounded above where they are in contact with the beach, but angular below. The beach is also overlain by a thin deposit containing angular blocks.

Dunlop[2] has described and figured a raised beach in the main road cutting about 450 yards west of St. Clement's Church. The vertical extent of the beach is about 20 feet, and it is covered with head. The height is estimated as 70 feet above O.D., a serious under-estimate. The section is now overgrown and only the lowest part can be seen. Its level is 110 feet, so that the top must be near 130 feet. The mean height of each of the beaches described is thus very near 120 feet above O.D.

The 125 ft. cave at Les Thielles, Guernsey, almost certainly belongs to this beach.

Danby[3] mentions, on hearsay evidence, a fossiliferous raised beach with shells of modern species 100 feet above sea-level near La Pulente, Jersey. Nothing further is known of this.

HIGH LEVEL TERRACES IN JERSEY.

In the absence of well-defined pebble beds a study of the shape of the ground may give us some information regarding planation at higher levels. The writer has attempted such a study in Jersey.

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[1] T. E. Naish, "Raised Beach—South Hill": *Bull. Soc. Jersiaise*, ix, 1919, 117–121.

[2] A. Dunlop, "On the Pleistocene Beds of Jersey": *Bull. Soc. Jersiaise*, vii, 1911, 112–120.

[3] T. W. Danby, loc. cit.

The cliff tops of the south coast appear flat and reference to the 2 in. Ordnance Map shows them to lie at about 200 feet above O.D. Inland, one of the largest level stretches of the plateau is that which lies at about 280 feet above sea-level in the north-east. There is another flat tract just above 400 feet around Les Platons, the summit of the island (450 feet). There is a brick-earth mantle over the whole plateau from 200 to 400 feet.

A more objective consideration of the levels of the island has been achieved by drawing a "hypsometric curve" (Fig. 1), plotting against the height of each contour the area which lies above it as a percentage of the total area. The curve will thus be flat at levels where the ground is flat and steep where the ground is steep.

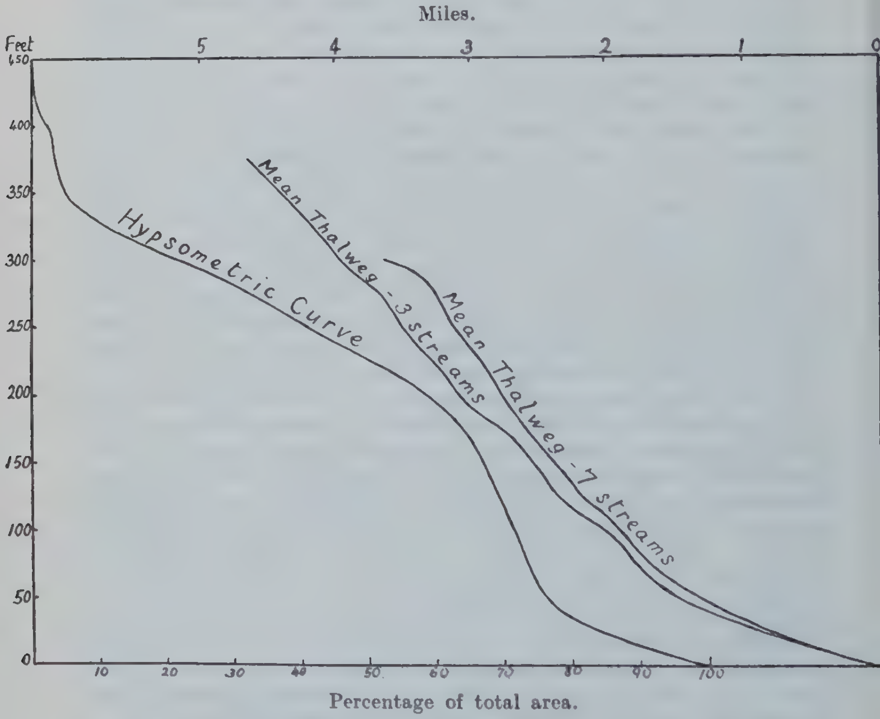

Fig. 1.—Hypsometric curve and mean thalwegs of streams, Jersey. The vertical scale of heights refers to all the curves. The horizontal scale of percentages refers to the hypsometric curve and that of miles to the thalwegs.

The only important breaks in the curve, as it grades down to sea-level, are at about 190 and 400 feet above that level. There is a trace of another at about 290 feet.

The 190 ft. break is of primary importance. It is clear that the main plateau of Jersey grades into a peneplain at about this level. Unfortunately no deposits have yet been found which are likely to have been laid down on the plain during its formation.

The vigorous onslaught of late Pleistocene marine erosion has usually left little but a cliff, now degraded, between the main plateau of Jersey and the modern alluvial plain. The longer streams, on the other hand, have a fairly gradual fall to sea-level, even below the 200 ft. contour. It is therefore of interest to see whether they show any signs of a base-level between 200 feet and the modern sea-level.

A curve has been included in Fig. 1 showing the mean thalweg of the longest seven streams in Jersey. Most of these streams rise just above 300 feet, and it is therefore unsafe to take into consideration the bend in the curve at about this level. The only other bend that seems to indicate a base level is that at about 100 feet.

The mean thalweg of three streams rising above 375 feet is too irregular to be of great value, but suggests base-levelling at many of the levels already found from other data.

SUMMARY AND CONCLUSIONS.

The terraces of the Channel Islands fall into well-defined groups. Beginning with the lowest, an ancient beach is found near modern mean sea-level in Jersey and Guernsey but practically nothing is known of its age.

The 25 ft. raised beach is ubiquitous and very well defined. It can be correlated with a similar beach in northern France and southern England. Its age is doubtful but it is probably interglacial and younger than the next-mentioned beach.

The raised beaches of Jersey, Guernsey, and Alderney at a height of about 60 feet, if all contemporaneous, were laid down near the beginning of Mousterian times. They agree well in height with the Monastirian terrace of Depéret [1] and are also probably to be correlated with the Portland raised beach which, according to Baden-Powell,[2] has a cold fauna.

Two raised beaches in Jersey at 120 feet and a high cave in Guernsey at 125 feet fall together. There is little evidence of their age. They are rather high for Depéret's Tyrrhenian terrace (93–100 feet), while near the upper limit of the latter falls the 100 ft. break in the Jersey stream courses.

The Jersey peneplain grading to 190 feet is probably represented in the other islands, but in the absence of closely contoured maps the level of the plateaux is not known exactly. The level is strongly suggestive of Depéret's Milazzian and of the "hemiplain" in the south of England which Wooldridge[1] tentatively correlates with the Milazzian. Wooldridge ascribes the 200 ft. level in England to late Pliocene or early Pleistocene times.

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[1] C. Depéret, "Essai de Coordination Chronologique Générale des Temps Quaternaires": *Comptes Rendus Acad. Sci.*, Paris, clxvi, 1918, 480–6.

[2] D. F. W. Baden-Powell, "Notes on Raised Beach Mollusca from the Isle of Portland": *Proc. Malacological Soc.*, xix, pt. ii, 1930, 67–76.

The 290 ft. platform in Jersey and the caves in Guernsey at 270 feet are to be correlated tentatively. They fall rather below Depéret's Sicilian terrace (300–330 feet).

Only Jersey rises above 400 feet. The 400 ft. terrace in this island, if due to base-levelling, is almost certainly contemporaneous with the Pliocene platform at the same level in the south of England.

The relations of the beaches and terraces to one another and to Depéret's terraces are shown in Figs. 2 and 3.

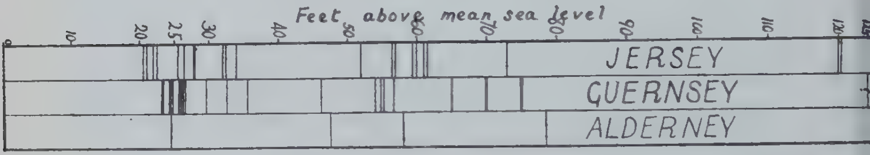

FIG. 2.—Measured heights of raised beaches in Jersey, Guernsey, and Alderney.

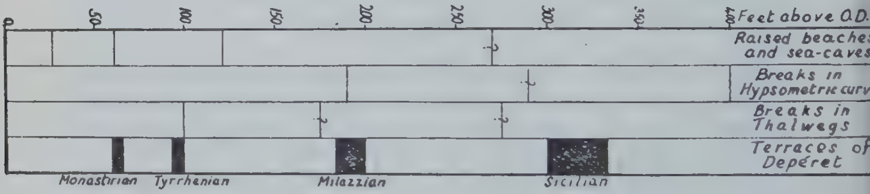

FIG. 3.—Mean heights of raised beaches and other probable base-levels in the Channel Islands, compared with the heights of the principal European Pleistocene terraces as determined by Depéret.[2]

The thanks of the writer are due to many members of the Société Jersiaise, and especially to Mr. E. F. Guiton for help in the field; and to Mr. D. F. W. Baden-Powell, Dr. R. R. Marett, and Dr. K. S. Sandford forcriticizing the manuscript of this paper.

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[1] S. W. Wooldridge, "The 200 ft. Platform in the London Basin": *Proc. Geol. Assoc.*, xxxix, 1928, 1–26.

[2] C. Depéret, "Essai de Coordination Chronologique Générale des Temps Quaternaires": *Comptes Rendus Acad. Sci.*, Paris, clxvi, 1918, 480–6.

Rejuvenation on Akpatok Island: A Topographical Unconformity in North-Eastern Canada.

By IAN COX, B.A., Sedgwick Museum, Cambridge.

(PLATES V—IX.)

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VI. FAULTING ON THE CANADIAN SHIELD.
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I. INTRODUCTION.

IN the summer of 1931 the Oxford University Hudson Straits Expedition spent five weeks on Akpatok Island, Ungava Bay, North-Eastern Canada. It was then that the writer made notes which result in the following communication.

Akpatok (Eskimo: *Aukpat'tók*, " The Island of Guillemots "), which lies over 80 miles west of Cape Chidley (Fig. 1), is an island about 28 miles long and 14 miles wide. Apart from a mere mention of the island by Hudson (who sighted it in 1610 and called it " Desire Provoketh "), the literature of Akpatok consisted before 1932 of a report by Dr. Bell, of the Canadian Geological Survey, who landed there for a few hours at the end of last century,[1] a few remarks by Turner[2] (who evidently had not been there), and charts issued by the Admiralty.

The island consists of a horizontally bedded series of Ordovician limestones and has no indigenous igneous material.

A map of Akpatok Island was made during the stay of the Expedition by Captain C. M. Singer, R.E.; this (Fig. 2) proved of great value to the writer, who here wishes to express his indebtedness to that gentleman.

II. GENERAL TOPOGRAPHY.

Akpatok Island is a superb example of a " Topographical Unconformity ".[3] The prospect from the sea shows immediately that its physiography is the result of erosional work of two distinct ages: inland from the coast is a plateau varying in height from 600 to 800 feet, of thoroughly mature aspect, evidently the result of advanced peneplanation effected at some remote time. (It is not intended here to discuss the detail of this plateau, as a description of its surface features has already been published by the writer.) [1]

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[1] Robert Bell, *Summ. Rept. Geol. Surv. Canada,* x, 1897, 79.

[2] L. M. Turner, *Ethnology of the Ungava District.* 11th Ann. Rept. Bureau American Ethnology, 1889–1890.

[3] O. T. Jones, *Q.J.G.S.*, lxxx, 1924, 584.

The coastline, however, presents an entirely different character, for the island is strongly cliffed for the whole of its perimeter. This line of cliffs is broken along its length by gorges that have been eroded by streams, and in the cliff-sections the slopes of the mature and more ancient river valleys can be seen above the gorges. (Plates VIII*a* and VII*b*.)

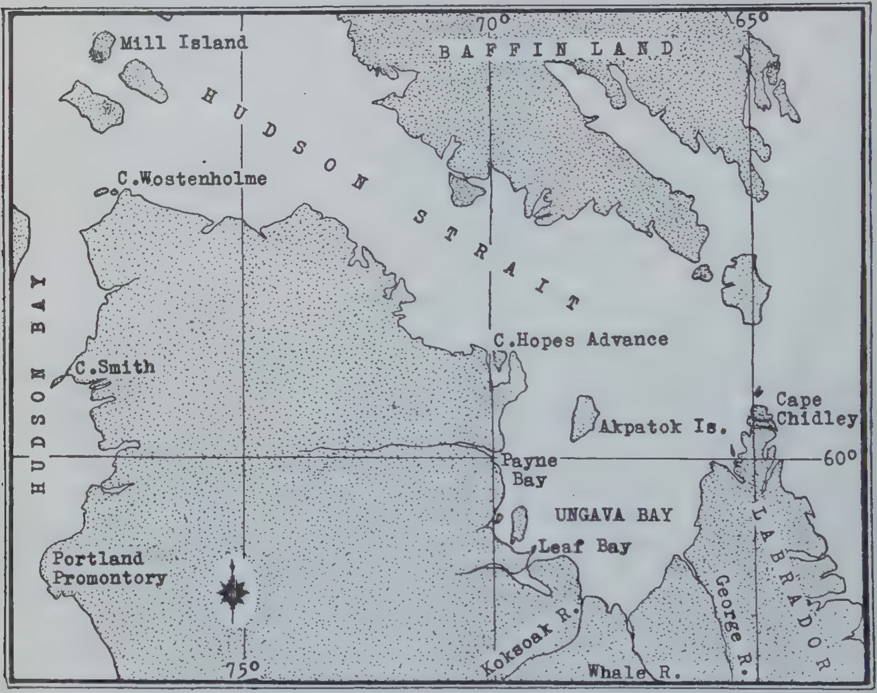

FIG. 1.—Sketch-map of North-Eastern Canada.

Inland from the coast all stages in the dissection of the ancient plateau by stream erosion can be seen; and when the valley floors are traced upward a discordance in grade becomes apparent.

From the superimposition of all these obviously young features upon a mature topography it is evident that here is a marked example of rejuvenation of the drainage system, which is now in process of modifying the original configuration of the land.

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[1] *Geogr. Jour.*, lxxx, 1932, 224 et seq.

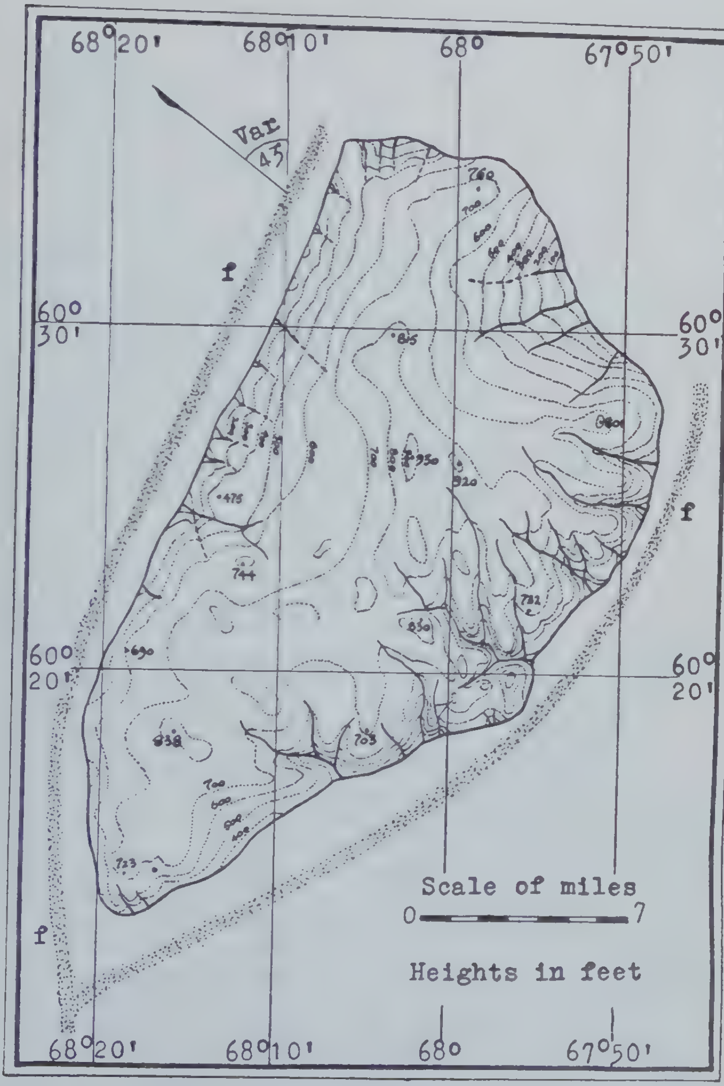

FIG. 2.—Akpatok Island, Ungava Bay. (Based on a plate in the *Geographical Journal*, vol. lxxx, by courtesy of the author, Mr. H. M. Clutterbuck, and the Royal Geographical Society.) f: zone of possible faulting.

III. Drainage.

(*a*) *The South and East Coasts.*

Although the period of the year during which water is unfrozen is relatively short,[1] the drainage system consists of a number of well-developed streams and their tributaries as well as a few swallow holes existing in the south-west of the island. The largest streams are found on the eastern side, where some tributaries reach as far inland as seven miles. It is proposed to consider one of these streams in detail, selecting for this purpose that which reaches the sea just north of the south-east point (Fig. 3*a*).

At its head the valley is exceedingly gradual and is first seen at about 850 feet O.D. as an ill-defined depression in the plateau which very gradually widens and deepens (Plate V*a*).[2] This stretch of the valley is thoroughly mature and, during August and September, there is no water in it. At a height of about 700 feet there is a considerable " hang " (Plate VI*b*) and the discordance in grade continues toward the sea. This produces at first a steepening in the valley side (Plate VI) and eventually a cliffed gorge, above which rises the bare ground that is a remnant of the pre-existing valley (Plate VII*a*). For the first mile of this gorge the cliffs are about 150 feet high and much encumbered with scree material. The floor of the gorge is about 30 yards wide. Along its length small and evidently young tributaries hang to it.

Above the confluence of the main stream and its principal tributary to the west there is a waterfall of about 50 feet in the flat bottom of the gorge. Below this waterfall the bare and perpendicular cliffs are replaced by steep detritus-covered slopes. The flat stream bed, furthermore, is deeply covered with limestone fragments and many erratic boulders. This wide ravine continues below the confluence, but becomes more constricted again immediately before the sudden bend eastward, where there is a second waterfall of about 50 feet, followed by further narrow gorge. At the bend another hanging tributary joins the main stream, descending to it down a waterfall of 150 feet.

In the reach from the bend to the sea, a length of a little under a mile, the stream runs in a very deep and narrow gorge cliffed for most of its course and with a waterfall of some 80 feet a quarter of a mile above the sea. Here the bed has no detritus but large erratics ; the immediate banks are limestone ledges from which the cliffs rise.

About 150 yards before the sea is entered a subsidiary stream joins the main and here the gorge suddenly widens (Plate VIII*b*).

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[1] In normal years from May until November.

[2] The majority of photographs are not of the described stream, but nevertheless illustrate the same features, if to a less degree.

The right bank continues as a cliff which joins the coast, but the height of the left bank ends suddenly in a spur between the main stream and the subsidiary. This spur has obviously been sharply truncated, but its terminal cliff (Plate VIII*b*, *a*) is masked by a slope of dry and unconsolidated limestone fragments (*b*); doubtless this deposit remains as witness of the immense amount of denudation that followed glaciation. (See below.)

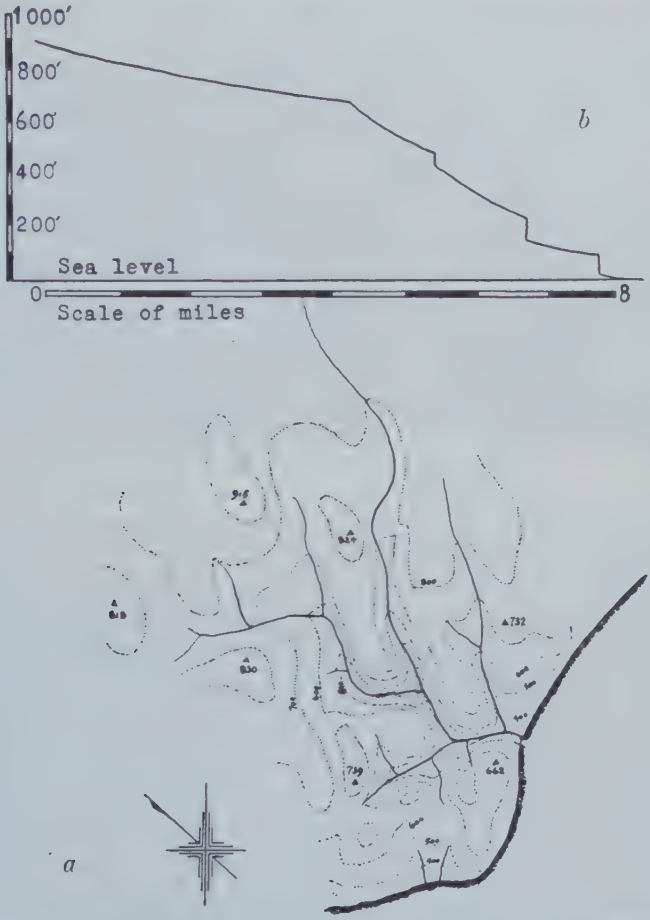

FIG. 3.—(*a*) Sketch-map of stream on the east of Akpatok Island. (*b*) Profile of the same stream. Both are on the same horizontal scale.

The two streams meet in a flat-bottomed lagoon area (*d*), bounded to the south by the gorge cliffs and to the north by a fairly steep

" meadow " slope rising to a height of 200 feet, where there is a slight terrace (due to stratification of the limestone) above which the ground rises rapidly to 450 feet. This lagoon has a floor of limestone shingle and rolled erratics, the former being piled up seaward to form a bar which continues the line of cliffs. At high tide the lagoon is filled with water, part of which seeps through from the sea and part being dammed back in the stream ; but at spring tides the sea may roll in over the top of this bar. At low tide, however, the stream follows an anastomosing course over the shingle, solid rock being nowhere visible. Some of the larger streams had cut a slight channel in the between-tide shelf. (See below.)

One phenomenon cannot be overstressed as an essential of the topography : remnants of the pre-existing and mature valley can be seen above the ravines and gorges throughout the whole length affected by rejuvenation. It is principally here that the little vegetation of the island occurs, forming the " meadows " near the sea whereon the visiting Eskimo choose to encamp.

The most significant point about the stream's course is brought out well in diagrammatic profile (Fig. 3*b*). This shows that below the head of rejuvenation (in the case of this stream, at 700 feet) there is a mere scramble of water down to the sea. The shortness of this rejuvenation-*thalweg* is even more apparent in the smaller streams, for, not having yet cut down their mouths to sea-level, they cascade down the cliff face. The step-like character of the profile is probably due to the horizontality of the limestone, although it is possible that it is due to the original cause of rejuvenation (considered below) reaching its present state by stages.

When the profiles of all the east coast streams are drawn out it becomes evident that the head of rejuvenation now stands at a general height of 600 feet. Naturally the more active streams have cut back to a higher level and thus the stream described above has reached 700 feet.

(*b*) *The Streams of the West Coast.*

In the south-west of the island there are no streams, and drainage is effected by swallow holes. The streams of the west are therefore confined to the centre and north of the coast.

The streams are definitely misfits in their present valleys. These are never more than a mile long and can collect but very little water even in the wettest season ; yet they are comparatively wide although largely filled in with detritus in which the channels of the present streams are cut. Their profiles all show a head of rejuvenation at about 400 feet. Since these streams lie relatively close together and their valleys are considerable they have the effect of cutting the cliff-line into short stretches, since the spurs separating one valley from the other are truncated. (See below.)

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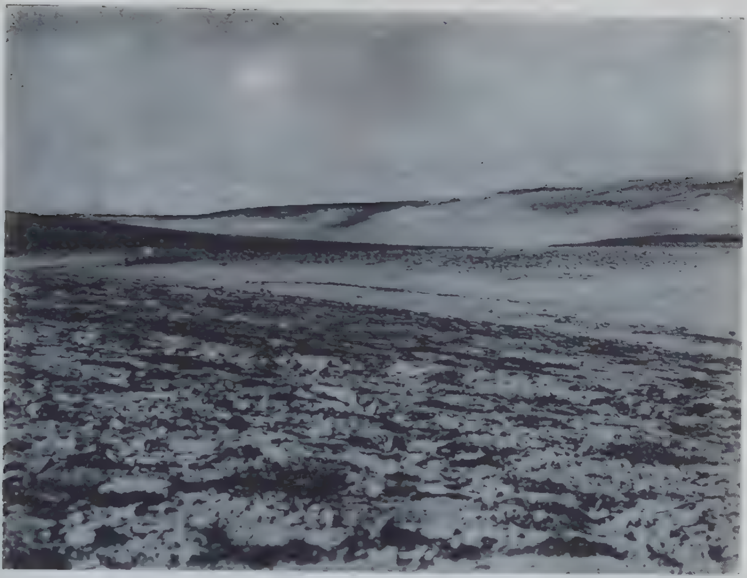
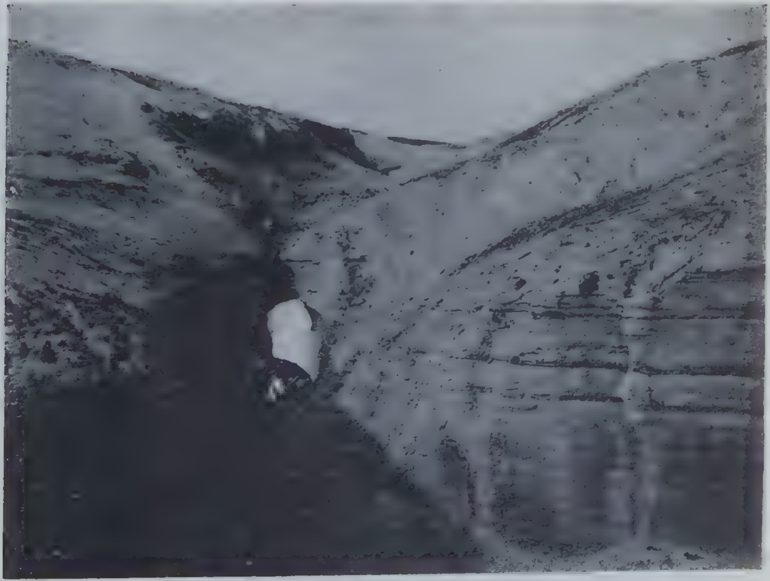
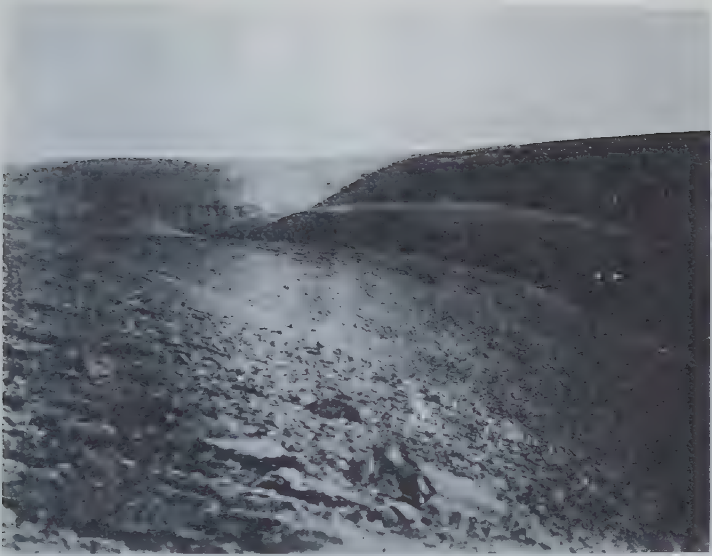


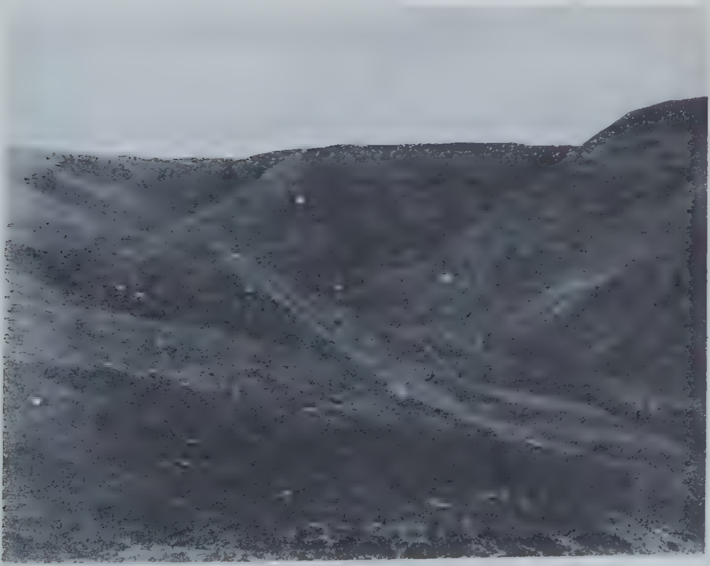
(*a*) PLATEAU AT ABOUT 700 FEET, AKPATOK ISLAND.



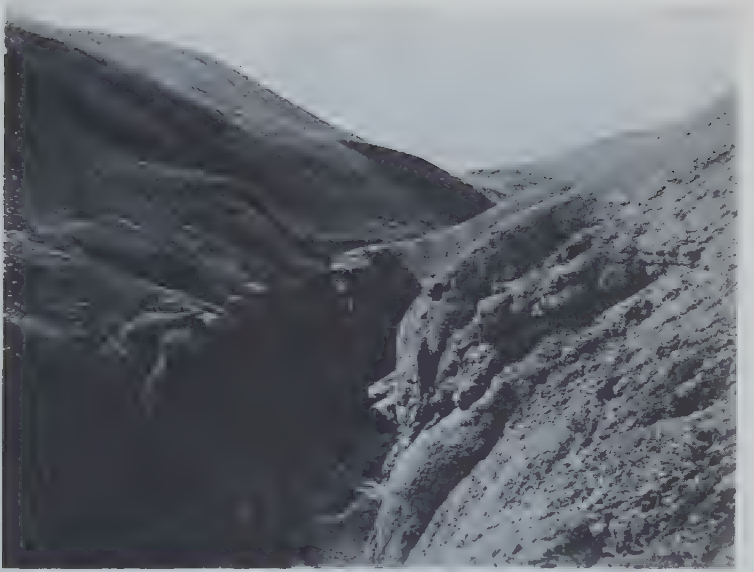
(*b*) HANG IN A STREAM OF THE SOUTH OF AKPATOK ISLAND. MATURE FEATURES IN BACKGROUND.



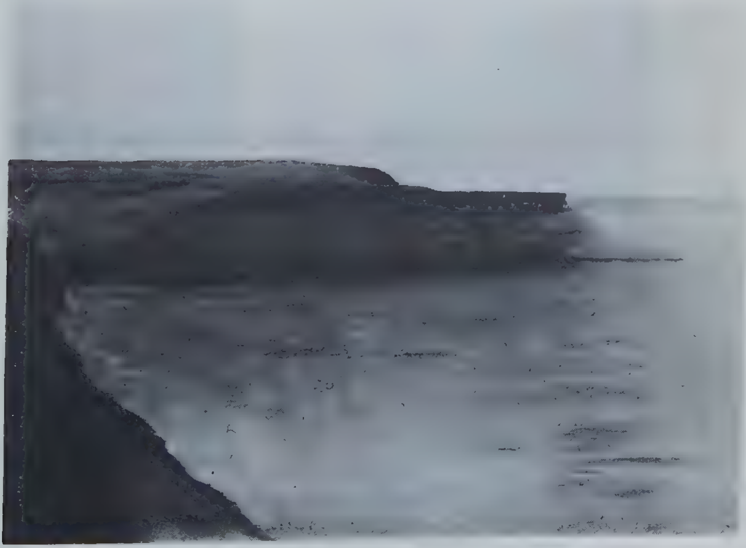
(*a*) PLATEAU AT ABOUT 600 FEET DISSECTED BY THE REJUVENATION OF STREAMS.



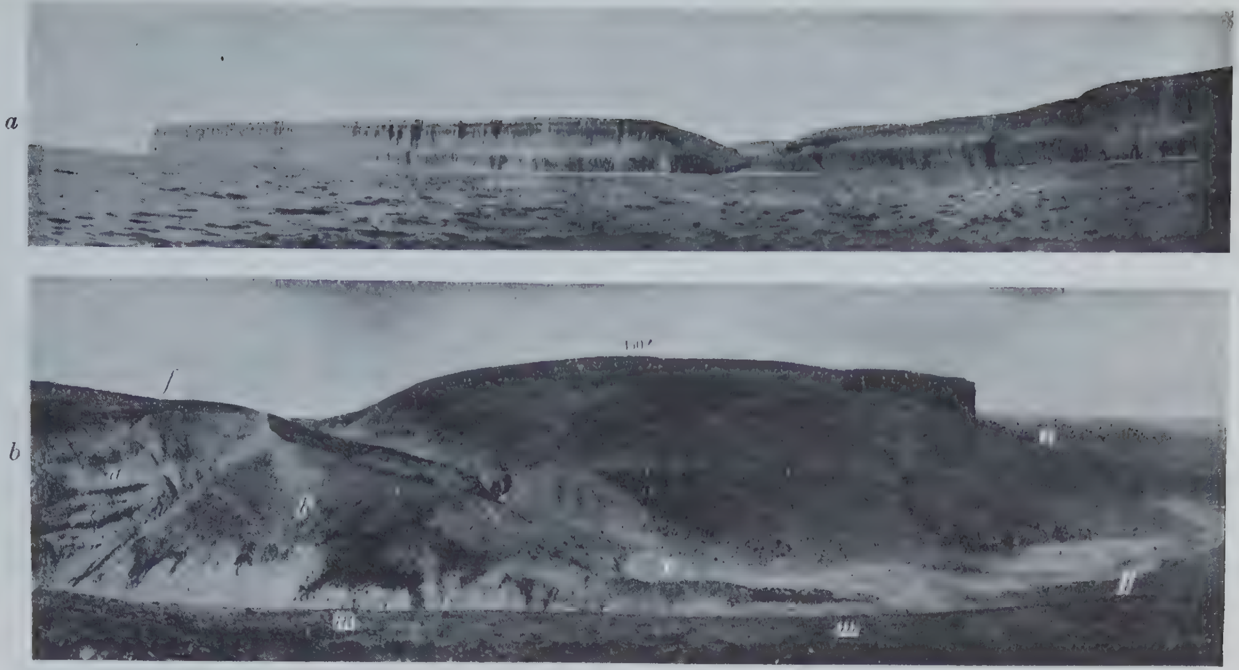
(*b*) REJUVENATED STREAM-VALLEY ON THE SOUTH OF AKPATOK ISLAND.



(*a*) SMALL GORGE ON THE SOUTH OF AKPATOK ISLAND. THE SLOPES OF THE PRE-REJUVENATION VALLEY CAN BE SEEN ABOVE THE GORGE.



(*b*) SMALL POINT ON EAST COAST OF AKPATOK ISLAND. REJUVENATION FEATURES ARE VISIBLE ON THE LEFT OF THE PHOTOGRAPH.



(*a*) SOUTHERN STRETCH OF EAST COAST.
(*b*) GORGE REACHING THE EAST COAST OF AKPATOK ISLAND. View from 450 feet, looking North: *a*, truncated spur; *b*, detrital slope; *c*, subsidiary stream; *d*, lagoon; *f*, mature topography; *m*, foreground concealing main gorge; *s*, between-tide shelf.

IV. COASTLINE.

A circumnavigation of Akpatok enabled the writer to sketch the whole of its perimeter. The island is bound along all coasts by perpendicular cliffs, varying from 100 to over 600 feet.

(*a*) *The North-East Coast.*

The cliffs reach a maximum height at the north-east point, where for a short distance they are over 650 feet. Here they fall perpendicularly to the sea but with two slight ledges formed along constant bedding-planes. Southward from here the cliffs fall rapidly in height and for 4 miles are at less than 100 feet. This is the least cliffed part of the island. However, in the next 3 miles the contours rise to 550 feet in the eastern cliff of the island. Throughout this length streams are very small, and have cut narrow, deep ravines in the cliffs. Where the coast is low valleys are correspondingly small.

(*b*) *East and South-East Coasts.*

From the eastern cliff to the south of the island, a distance of rather under 30 miles, the prospect from the sea is uniform, except that on the east stream-cut gorges are more frequent and to the north there is often sufficient detritus to mask the lower 300 feet of the cliff face. The height of the cliffs remains constant at some level between 400 and 500 feet, the only falls being entirely due to gorges. Some are as large as that already described, and in looking up them one sees excellently the topographical unconformity (Plate VIII*a*), but others are small and their bases cut the cliffs sometimes as high up as 400 feet.

In this stretch subaerial weathering seems to compare more favourably with that of the sea, producing a rounded brow to the cliffs. One small headland, indeed, appears to be formed entirely of scree lying at the angle of rest. (Plate VII*b*.) The cap of the point is a stratum of limestone in situ and its base the between-tide shelf, but the remainder of the profile is composed of angular fragments of frost-produced talus. The result is a headland of singular appearance and limited dimension, for laterally it terminates suddenly. Doubtless it owes its nature to the marine shelf diminishing the erosive action of the sea (thus preventing removal of debris), while frost is able to work on several sides (Plate VII*b*).

The marine shelf is well developed on this coast. It is about 70 yards in width and slopes very gradually seaward to end suddenly. Usually the shelf, which is covered at high tide, is swept clean of debris, but at the foot of the cliff a narrow beach of shingle may be thrown up and behind it lies a wave-cut notch. Most often the shelf is eroded down to the level of one stratum, but here and there, where the process of planation is incomplete, one may see "tables" of higher strata isolated by narrow sea-cut channels washed out along the joints (Plates VIII*b*, *s*, and IX).

A glance at the map shows how unindented is this coast; the major headlands are most blunt and even in detail the outline is unrelieved (Plate IX).

(*c*) *The West Coast.*

The west coast of the island is singular in two respects: in the first place, it is most remarkably straight, the northern 21 miles being phenomenally so, and it is only a slight change in direction at one point that prevents the entire length from being completely straight; secondly, north of the change in direction cliffs attain a uniform height of 250 feet.

The coast south of the change in direction closely resembles the south coast, except that streams are non-existent. The general height is 500 feet.

Thirteen miles from the south point comes a sudden change, very remarkable as seen from a ship, for as far as the eye can reach along the straight coast (already mentioned) are lengths of cliff no more than a mile long, each resembling its neighbour and separated from it by a ravine cut down to sea-level. This is where the short streams already described reach the sea. The cliffs have lost the perpendicular character seen on the other coasts and incline at a less steep angle, no doubt because the sea is unable to remove the detritus lying thick on the foreshore, while frost can only work effectively at their brow, the foot being masked by the accumulation of talus. Northward, where the streams become more widely spaced, detritus decreases, perpendicularity returns, and the cliffs assume an arcuate form.

(*d*) *North Coast.*

The north-west point of the island is formed of a 450-ft. cliff with a pronounced wave-cut notch. Eastward the coast soon falls to 100 feet and becomes well "screed up". The three watercourses reaching the sea here are small and cut correspondingly narrow notches in the low cliff. The slight headland terminating this stretch is 150 feet in height and also has a pronounced wave-cut notch. The remaining 4 miles increases gradually in height in vague terraces, defined by stratification, to the cliff of 650 feet with which this survey began.

V. Causes of Rejuvenation.

Rejuvenation may be originated by the following causes, working severally or in conjunction: (i) uplift; (ii) betrunking by (*a*) faulting, (*b*) intense marine retrogradation; (iii) piracy or increased volume of streams. A cursory glance dismisses the latter cause; there is no possibility of piracy in this case, and rejuvenation on account of increased volume is manifest principally in the phenomenon of "cutting back" and will take place without a change in level at the stream mouth, where the rejuvenation features are so apparent on Akpatok Island.

(*a*) *Uplift.*

Features of rejuvenation produced by uplift have been admirably described by Professor Jones in his discussion of the Towy drainage.[1] Such features are developed markedly on Akpatok Island, where we have seen gorges cut in the floor of a mature valley, a head of rejuvenation above which lies a mature *thalweg*, and an ungraded reach below this head. However, such features could equally well be produced by betrunking as will be seen. It is necessary therefore to examine what evidence there is of recent uplift in these parts.

The writer found no traces of raised beaches on the island, although it must be mentioned that circumstances prevented him from examining the northern shores closer than from a schooner. Yet it must be borne in mind that the island is very open to marine attack as well as marked subaerial erosion, and thus there is every possibility of raised beaches having been removed. The evidence that the island affords therefore is indirect as well as slender.

The spur separating the streams that meet in the lagoon above described is truncated and given a cliff face (Plate VIII*b*, *a*). Such truncation could in no wise be due to fluviatile action ; it is therefore possibly a relic of erosion by a sea that stood higher than the present. If this were so it must have been rapid erosion, since the detritus slope, obviously a remnant of rapid post-glacial denudation, masks its face and, as will be subsequently shown, the only recent depression, if it existed here, was due to glaciation. At the same time it is possible that frost erosion could produce a vertical face on the Akpatok limestone provided that detritus falling to the foot were removed (either by the sea or by the streams).

Immediately north of the north-east point the cliffs are less than 100 feet in height ; behind them stands a scar that may possibly be a raised sea cliff, but, as in the case above, it may be a frost feature with its base buried in debris. Unfortunately this was only seen from the sea and was not visited.

Nor does the presence of shingle and detritus on the floor of the lagoons, or the idle stream-cut channels in the marine shelf (a feature that must have been developed subsequent to gorge cutting and when sea-level was lower than now) assist, since these represent a period of aggradation later than the formation of the gorges.

And, again, the ledges on some cliff faces (Plate VIII*a*) do not appear to be necessarily due to past marine action, since they occur at such places as gorge corners where frost action has extra surface on which to work, and, the sea being inactive after passing the bar of the lagoons, can act far more effectively than the latter agent. It is natural that such weathering should cease at a definite beddingplane. The ledges cannot be compared satisfactorily with the benches in northern Labrador described by Daly.[1] " Benches and stray wave-cut sea cliffs, at all elevations up to the highest shoreline, appear at almost every exposed point in Labrador. . . . Very rarely are the benches of great breadth or length, nor are they usually horizontal. They have been developed by rifting on gently curving master joints. They are not the continuous horizontal terraces of our text-book diagrams. The benches cannot be taken to mean so many halts during the process of elevation, but are rather determined in size, form, and position by the controlling planes of jointing." But as Cooke[2] points out: " The benches are evidently formed by erosion; and as they are found only between the present level of the sea and the highest post-glacial level and on exposed points, the eroding agents were evidently the sea. . . ."

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[1] O. T. Jones, *Q.J.G.S.*, lxxx, 1924.

The final piece of evidence from the island itself is an isolated boulder from a stream bed at about 450 feet. This was composed of large fragments of the island limestone and a very little glacial material (comparable to metamorphic erratics in composition) set in a calcareous cement, and associated with this a portion of a bed of comminuted island limestone with fragments of exotic metamorphic material and much millet seed quartz; this too was set in a calcareous cement. Now this may be a raised beach deposit and it is particularly unfortunate that none was found in situ. On the side of one ravine cliff at about 600 feet another example of the coarser component of such a deposit was found, but its relation to the country rock could not be determined owing to the immense quantity of scree material which masks everything.

Evidence on the island itself being slender, it is necessary to consider recent changes in level on the shores of Ungava Bay. Fortunately Dr. H. C. Cooke, of the Canadian Geological Survey has recently published three papers on " The Physiography of the Canadian Shield ",[3] which deal with the Labrador peninsula in considerable detail.

" The Labrador peninsula," he concludes,[4] " has undergone peneplanation and . . . since its formation the peneplane has been tilted into its present position. In general the south-east corner was uplifted most, giving the whole area a tilt to the north-west toward Hudson Bay and Ungava Bay where it passes below sea-level. Local warpings have affected the north-east and north-west corners, around Capes Chidley and Wostenholme, tilting these parts of the tableland sharply toward the east and south, respectively. . . . The uplift of the Labrador plateau is . . . dated as fairly late Pliocene."

Cooke has also considered raised beaches due to glacial depression, collecting and correlating the data of various authors and recording them as isobases.[1] Post-glacial "uplift was greatest, 600–800 feet, on the Hudson Bay side of the Labrador peninsula, and throughout the area south as far as Ottawa. . . . It was least on the Atlantic coast, decreasing to a minimum at the extreme end, Cape Chidley. . . . Between Portland promontory and Cape Smith, a straight line distance of 150 miles, the shores are low, so that there is no possibility of determining the ancient shore line. This low area extends completely across the peninsula to Payne Bay, on Ungava Bay, and is nowhere more than 500 feet above sea-level. It is probable that it was completely covered by the sea at the close of the glacial period. . . . All evidence cited indicates that the late Quaternary uplift of Labrador peninsula has been greatest on the Hudson Bay side and decreases to a minimum at the north-east corner where near Cape Chidley it has been only 225 feet."

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[1] R. A. Daly, *Bull. Mus. Comp. Zool.*, xxxviii, 210.
[2] H. C. Cooke, *Trans. Roy. Soc. Canada*, **3**, xxiv, 1930, 76.
[3] H. C. Cooke, *Trans. Roy. Soc. Canada*, **3**, xxiii–v, sec. 4, 1929–1931.
[4] Ibid., xxiii, 1929, 117.

The highest raised beaches recorded on the shores of Ungava Bay are: At Payne Bay, 325 feet[2]; at Leaf River, 250 feet[3]; at the mouth of Koksoak River, 300 feet[2]; at the mouth of the George River, 300 feet.[2] Now if Akpatok Island reacted in the same way as the rest of Ungava to the glacial load (and the abundant presence of glacial material on the island shows that it was certainly covered by ice) raised beaches would be expected at a height nearer 300 feet than 200. This is an estimation from Cooke's map of isobases; it can be no more accurately determined because the plotted isobases turn suddenly parallel to the south shore of the bay before swinging north. (This deviation is not shown in the map drawn by Fairchild,[4] whose isobase 400 feet is seen to pass through the mouth of the George River, where Low[2] showed the beach to occur at 300 feet.) Doubtless this bend in the isobases represents an incomplete recovery from the glacial burden.

Cooke[5] considers that the "Hudson Straits . . . exhibits many evidences of being still considerably below its pre-glacial level. There is as yet little information from which one may estimate how far it is below that level. The only evidence available indicates that it is at least 400 feet". Such a condition he has shown definitely to obtain in Hudson Bay, which "has not existed as an inland sea for any long period of time, but . . . has recently been drowned. As depression is known to have occurred in glacial time, it is natural to accept this as the time of drowning". And in Ungava Bay in particular "still another evidence of drowning is afforded by the long currentless ends of the streams entering Ungava Bay". The writer's observations of northern Labrador agree with those of Cooke "that the Labrador coast once stood higher than at present, and is now submerged or drowned". Indeed one might conclude the same from a glance at photographs such as those figured recently by Forbes.[1]

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[1] Ibid., xxiv, 1930, 51 and fig. 4.
[2] A. P. Low, *Geol. Surv. Canada, Ann. Rept.*, xi, N.S., 1898.
[3] A. P. Low, Ibid., ix, N.S., 1896.
[4] Fairchild, *Bull. Geol. Soc. America*, xxix, 1918.
[5] H. C. Cooke, op. cit., 70–3.

Even if it be considered that Akpatok Island has risen 300 feet since glaciation the rejuvenation could barely be accounted for, since extrapolation of the mature valley reaches a contour of 300 feet much further from the present coast than, it would seem, the sea could erode the island limestone in post-glacial time. Presently further and more slender evidence will be shown to imply a pre-glacial age; but it is inconceivable on its face value that peneplanation of the completeness of the Akpatok plateau could be effected in so short a time as that occupied by post-glacial depression.

(*b*) *Retrogradation.*

It is not difficult to see that any agent of normal weathering will give abrupt features when working on a horizontal and homogeneous series such as the Akpatok limestones, provided that the waste material is removed. Such a situation was realized long ago, and in 1907 Hinxman[2] summarized it thus: "The denuding forces acting on a series of rocks very homogeneous in composition and arranged in gently inclined or horizontal strata, tend to produce outlines at once simple and massive and more or less architectural in form"; and one may consider the seaward slopes of the plateau especially on the south-west of the island,[3] with the same author: "A closer examination of these slopes shows also that their smoothness is more apparent than real, seeing that they consist of a series of alternating dip slopes and basset edges which give rise to successive low terraces that follow one another in parallel lines along the hillside." Thus there is nothing very unusual in the form of the Akpatok cliffs, but their magnitude and straightness need further explanation.

A horizontally bedded compact limestone series is very resistant to marine erosion; one can see from the wave-cut notches that the sea has removed all that is lost and has been unaided by any intrinsic tendency to disintegrate in the rock. Thus for the sea to have retrograded a newly emerged coastline sufficiently to give a perpendicular cliff of 650 feet and a coastline of cliffs of 450 feet for 30 miles necessitates the conception of a considerable length of time. Nor is this all; at the end of such time the difference in depth of coastal erosion in an unbroken cliff stretch and that at a mouth of a stream would, one might well suppose, be considerable. On Akpatok this difference is characteristically slight. It is apparent that the sea has eroded away 70 yards, for this is the width of the between-tide shelf, but soundings beyond (7½ fathoms m.s.l., 1,000 yards off shore) help no further in elucidation, since such shallowness might well be due to detritus removed during the course of erosion.

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[1] Alexander Forbes, *Geog. Review*, xxii, 1932, figs. 3–6.

[2] *Mem. Geol. Surv. Scotland*, "Geological Structure of N.W. Highlands," 1907, 271.

[3] I. H. Cox, op. cit., 226.

Nevertheless, the sea must remove a considerable amount of detritus, for, in an area where frost-weathering is so marked, were the fragments produced by erosion not removed, the whole island would be very soon buried beneath its own debris. Where the sea is an active agent of transportation, as on the east coast of Akpatok Island, the cliff features are perpendicular, but on the west coast, where debris has not been removed from the foot of the cliffs the abrupt character is masked. Were there evidence of a marine shelf extending for several miles off the coast of Akpatok Island, it might seem possible that the difference in height between the west and east coasts, and hence the rejuvenation, was entirely due to the removal of debris on the east (where frost therefore can continue to erode) and the accumulation of debris on the west (where frost erosion is considerably retarded by detrital masking). However, as stated already, the shelf is only 70 yards wide.

There are, of course, cases where retrogradation alone has betrunked streams and caused them to hang suddenly at the cliff edge; a glance at the South Kent coast will reveal many such.[1] But one wonders whether, if these valleys were no longer dry, the coastline would not now be very much more indented. Chalk, too, is a much less resistant substance than the Akpatok limestones, and the English Channel flowing through a confine with considerable tide race and armed with indigenous flints must have excellent eroding power. In Caithness there are magnificent cliffs of fairly horizontal sandstones, doubtless produced by marine retrogradation alone, but in this region rivers reach the sea in a more mature manner and often with a bay at their mouths. Here, then, fluviatile erosion has kept pace with that of the sea, which in this part is far from inconsiderable.

It seems unreasonable therefore to believe that the rejuvenation here is produced by intense subaerial erosion and marine retrogradation alone.

(c) *Faulting.*

There is yet one agent that would instigate marine erosion and account for all these features for which an explanation is being sought. It is faulting. A fault which, bifurcating south of the island, gives two subsidiaries, one with downthrow to the west running parallel with the west coast, and the other with the south-east coast and bending northward parallel with the eastern coast with downthrow to the east, would leave the island as a small horst (Fig. 2). The immediate effect of such movement will be the production of fault-scarps upon which the sea will commence erosion (Fig. 4, 2). The rivers, suddenly betrunked, will reach the sea by a plunge down the fault-scarp and will start to cut down and back, producing gorges in an attempt to find the curve of grading characteristic of maturity[1] (Fig. 4, 3). Head-waters,

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[1] See D. W. Johnson, *Shore Processes and Shoreline Development*, 1919, pl. xliii.

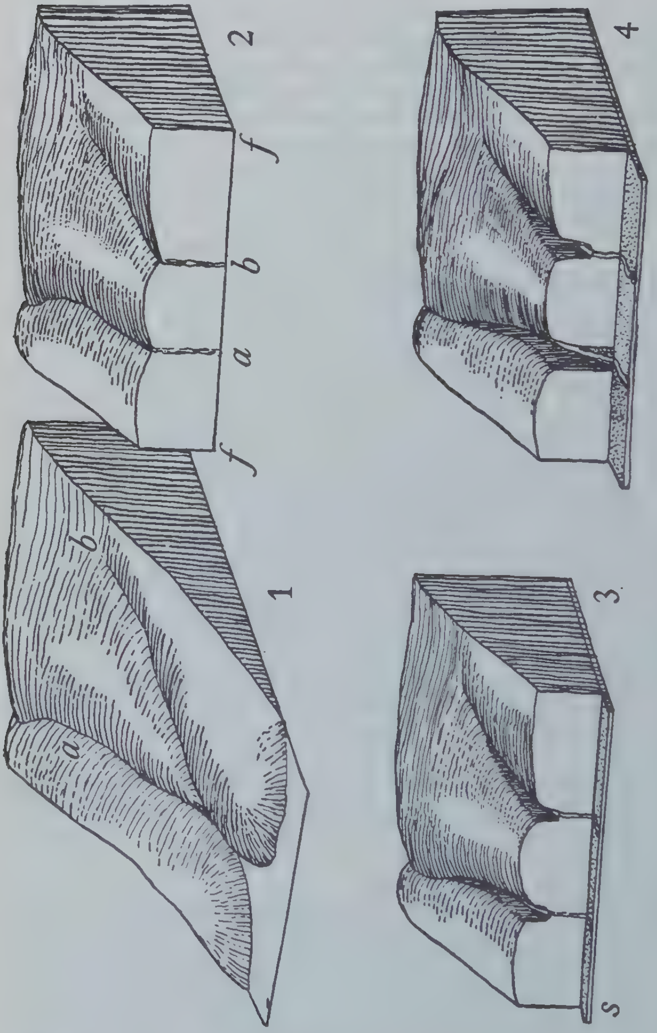

FIG. 4.—Diagrams illustrating the effect of faulting on a mature topography with watercourses when the downthrow mass is below sea-level. (1) Mature seaward topography. *a*, *b*: Two streams, the latter less active. 2. Coastline produced by faulting (*ff*). Streams fall to the sea. (3) Gorges produced by downcutting; shelf (*s*) due to marine retrogradation. (4) Stage subsequent to 3; the gorge mouth of *a* has reached sea-level.

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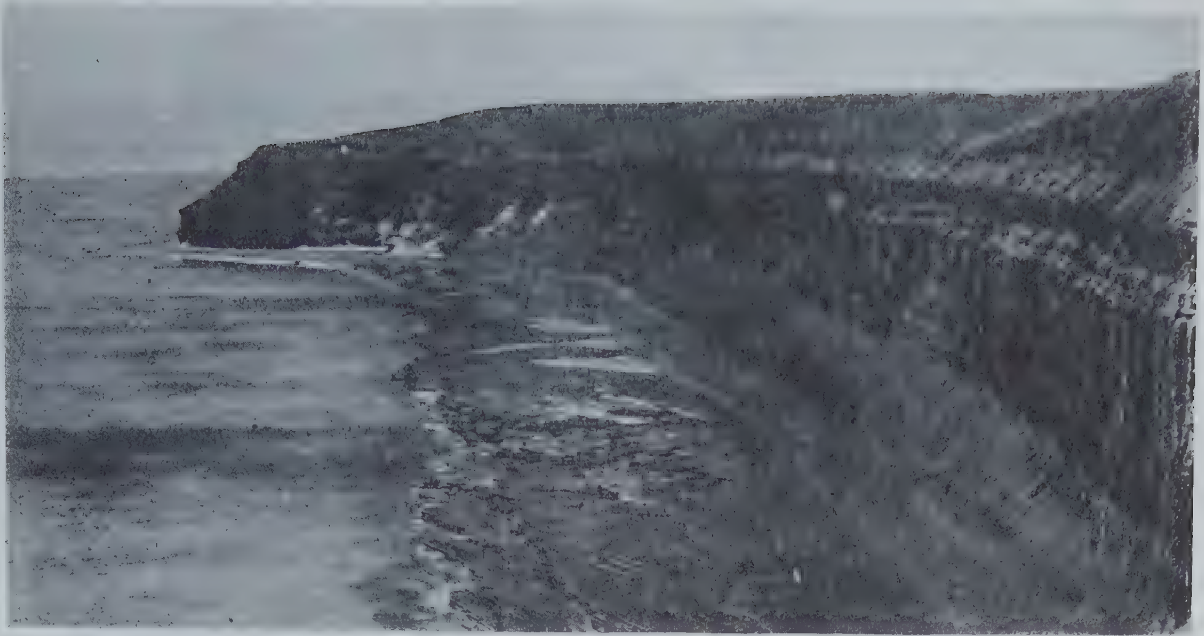
[1] O. T. Jones, op. cit.



On the East Coast of Akpatok Island. The between-tide shelf is visible.

[To face p. 80.

cut off above their confluences, will reach the sea independently and deprived of much of their former power to cut back (Fig. 4, 2). Such is the situation already shown to occur in the misfit streams of the west coast of Akpatok Island. Further, the initial coast would be straight, yet dropping suddenly to the sea so that frost and marine erosion in little time could make it perpendicular.

The northern coast, with its lower country and smaller cliffs, as well as perhaps the north-east coast, possibly represents an area of foundering; the 650-ft. cliff between them standing as an unfoundered element.

The radial disposition of the small streams cannot pass without notice. At a first glance it might appear that this were due to the present island nature of the country. But, since the head of rejuvenation in all the streams of the same coast is approximately at the same height and because the magnitude of their beds is evidence of work done by presumably a far longer stream, it is much more probable that they owe their trends in the first place to the geometrical axis of the island being a watershed, from which in pre-isolation time these streams would flow as head-waters to rivers now obliterated by faulting.

VI. Faulting on the Canadian Shield.

"The (Pliocene) elevation (of the Labrador peninsula) was accompanied by faulting in the Lake Temiskaming basin, at the mouth of the Hamilton river, along the north shore of the Gulf of St. Lawrence, and in other placess . . . . Mawdsley[1] has collected a considerable volume of evidence to show that the lower land around the Gouffre river (which enters the Gulf of St. Lawrence) is separated from the high region in the northern part of the map area by a series of faults, which topography and other features indicate to be of comparatively recent date. Presumably the faulting occurred during the general uplift of the Labrador plateau. . . . These faults in all cases are marked by high straight scarps which, in certain instances at least, are clearly not formed by differential erosion (fault-line scarps) because the rocks on both sides are the same. The scarps are deeply dissected by the valleys of small streams, in the gradients of these valleys, though steep, are fairly uniform. . . . The Lake Temiskaming scarp is broken by the deep gorge of the Montreal river, called the Notch, a narrow canyon 3 miles long through which the river descends in almost continuous rapids to the level of the lake." (I.e. the river has obviously not yet established a mature grade.) "This deep dissection of the fault-scarps, by which comparatively small streams have attained uniform gradient, appears to mark the faulting as occurring along with the general uplift, as might be expected. Many of the faults, of course, may have existed prior to uplift and movement along them may merely have been renewed at this time."[1]

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[1] J. B. Mawdsley, *Mem. Geol. Surv. Canada*, 152, 1927.

On the Koksoak River Low[2] has suggested that some of the *cuesta* valleys have been formed by faulting. Of the area south of James Bay Kindle[3] has written: "It is evident . . . that the pre-Cambrian rocks would, if the heavy mantle of Quaternary deposits were absent, show one or two scarp-like slopes, facing northward toward the Palaeozoic plain. The only probable explanation of this physiographic feature is the presence of one or more faults at the contact of the two great series of rocks." For a fault-scarp of this nature to survive Pliocene peneplanation imputes to itself a late date.

In the north of the Hudson Straits there is the evidence of Gould[4] concerning islands which show "Rectangular fracture-fault system, which is fairly spectacular in the perfection of its development and admirably exposed . . . one set of fractures has a strike of N. 40° E., and at right angles to it a second set equally prominent. Scarps of 50 feet are common along these lines and there appears to have been some block-faulting. One rectangular valley within the island has originated in this manner, and the large island to the south-east of Mill Island proper is separated from its parent mass by a 'graben'".

VII. Conclusion.

Evidence of recent faulting on the Canadian Shield, then, is not lacking; and since it seems by far the most satisfactory way in which the physiographical problems of Akpatok Island may be explained, it may be accepted as definitely as is reasonable where there is no direct evidence. In the light of this, it is not difficult to date the plateau.

The ravining is apparently pre-glacial, as has been seen from a consideration of glacial depression, the abundant erratics in the stream beds, as well as a deposit of blue (?) glacial clay found piled up in one ravine. This recalls a remark of Cooke's[5] that "In limestone areas the drift is a dense blue clay carrying very few pebbles". It has already been shown that the Labrador plateau underwent peneplanation until late Pliocene time when movement occurred. The rivers of this plateau must have been initiated between middle and late Pliocene time, and some, such as the Hamilton and Saguenay, maintained their courses by cutting down against the regional uplift.[6] The Akpatok plateau, it seems, can well be correlated with that of Labrador. When the Ungava area sank at the end of Pliocene time, presumably the island, dissociated from the foundering country around it by faulting, remained as a stable block.

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[1] H. C. Cooke, op. cit.

[2] A. D. Low, *Geol. Surv. Canada, Ann. Rept.* 13, n.s., 1900.

[3] E. M. Kindle, *Geol. Surv. Canada, Summ. Rept.*, part ci, 1923.

[4] L. M. Gould, *Geogr. Review*, xviii, 1928.

[5] H. C. Cooke, op. cit., xxiv, 56.

[6] H. C. Cooke, op. cit., xxiii, 1929, 119.

Hitherto the limestones have been considered horizontal; actually this is not strictly true, for a dip of 2–3° was observed to the west in one place. Since the cliff line reflects this dip, being 250 feet high in the west as opposed to 450 feet on the east, it might be assumed that the faulting at this time gave the island that inclination, for when features reflect such minute structures the structures might well be recent.

Of the fate of Akpatok during and immediately after glaciation little can be said with certainty, except that possibly there has been subsequent to the gorge cutting a slight drowning followed by emergence. A suggestion that the island now stands a few feet lower than formerly is afforded by stream-cut channels in the between-tide shelf.

The writer is greatly indebted to Professor O. T. Jones, F.R.S., for reading the manuscript and offering many helpful criticisms; also to Professor F. Debenham, Dr. O. M. B. Bulman, and Mr. M. Black for suggestions with regard to the manuscript. He wishes gratefully to acknowledge grants from the Governing Body of Magdalene College and from the Worts Fund in Cambridge.

EXPLANATION OF PLATES V–IX.

Plate V.

(*a*) Plateau at about 700 feet, Akpatok Island.
(*b*) Hang in a stream of the south of Akpatok Island. Mature features in background.

Plate VI.

(*a*) Plateau at about 600 feet dissected by the rejuvenation of streams.
(*b*) Rejuvenated stream-valley on the south of Akpatok Island.

Plate VII.

a) Small gorge on the south of Akpatok Island. The slopes of the pre-rejuvenation valley can be seen above the gorge.
(*b*) Small point on east coast of Akpatok Island. Rejuvenation features are visible on the left of the photograph.

Plate VIII.

a) Southern stretch of east coast, Akpatok Island. Mature features are visible inland.
(*b*) Gorge reaching the east coast of Akpatok Island. View from 450 feet, looking north. (*a*) truncated spur; (*b*) detrital slope; (*c*) subsidiary stream; (*d*) lagoon; (*f*) mature topography; (*M*) foreground concealing main gorge; (*S*) between-tide shelf.

Plate IX.

On the east coast of Akpatok Island. The between-tide shelf is visible.

Notes on the Tablazo Faunas of S.W. Ecuador.

By R. Wright Barker, B.A., F.G.S.

THE Tablazos or Quaternary raised beach deposits of the West Coast of South America have attracted attention for a considerable time, as evidence of recent changes in sea-level. Early accounts of those occurring on the more southerly portion of the Continent are given by d'Orbigny in his *Voyage dans l'Amérique méridionale* and by Charles Darwin in his *Observations on the Geology of South America.* The Tablazos of Peru received considerable attention in Dr. Bosworth's work (1)[1] and a brief sketch of the fauna was given.

As long ago as 1874 Dr. Theodor Wolf (7) published an account of the Quaternary deposits of Ecuador, and a further more detailed description in 1892 (8), but these accounts were of a very general descriptive nature and little reference was made to the fauna of the raised beaches. The following (from his *Geografia*, 1892, 286–7) includes most of his remarks on the fauna :—

> " . . . In numerous places, almost all in the neighbourhood of Santa Elena, the strata are full of remains of marine organisms. The greater part appear to belong to living species and are fresh or slightly decalcified. Close to Santa Elena, one finds quite commonly, in the topmost beds, large bones and molar teeth of the Mastodon and other mammals which became extinct in the Quaternary, which have given rise to the fable of the giants of the coast of Santa Elena. Some remains have also been found between St. Lucia and Balzar. The Mastodon is the *Mastodon andium*, and is identical with that found in the volcanic deposits of the inter-Andine region. I believe that the horse of the coast, of which the molars are found with the remains of the Mastodon, is the same as that of the Quaternary of the Sierra, named by Wagner and Bianco *Equus andium*. . . ."

More recent accounts by Dr. George Sheppard (3, 4, 5, 6) give descriptions of the topography and lithology with little or no reference to the included fossils. As the writer had the good fortune to make small collections from various localities in the Santa Elena Peninsula, it was thought desirable to compile a few brief notes on the general character of the fauna, for comparison with that of Peru, a little further to the south. For general particulars of the geology reference may be made to the papers by Dr. G. Sheppard, referred to in the bibliography at the end of the present paper.

Many of the beds are typical " shell-banks " made up of broken and rolled shells, the spaces between being filled with sand and shell fragments. The cementation varies, being considerable in some localities, and almost non-existent in others, and, indeed, usually varying from bed to bed in the same locality. Such cement as there is, is of a calcareous nature, and in some of the beds gives rise to a hard calcareous sandstone from which it is difficult to extract the fossils without injury.

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[1] Numbers in parentheses relate to bibliography at the end of the paper.

The shell-banks, all typically littoral in character, alternate with current-bedded sands and sandy limestones, the series passing upwards into terrestrial deposits of a loess-like character. The included fauna, as Wolf noted, is principally molluscan, consisting of species now living off the coast, but the beds also contain large numbers of barnacles, and in some places, echinoids.

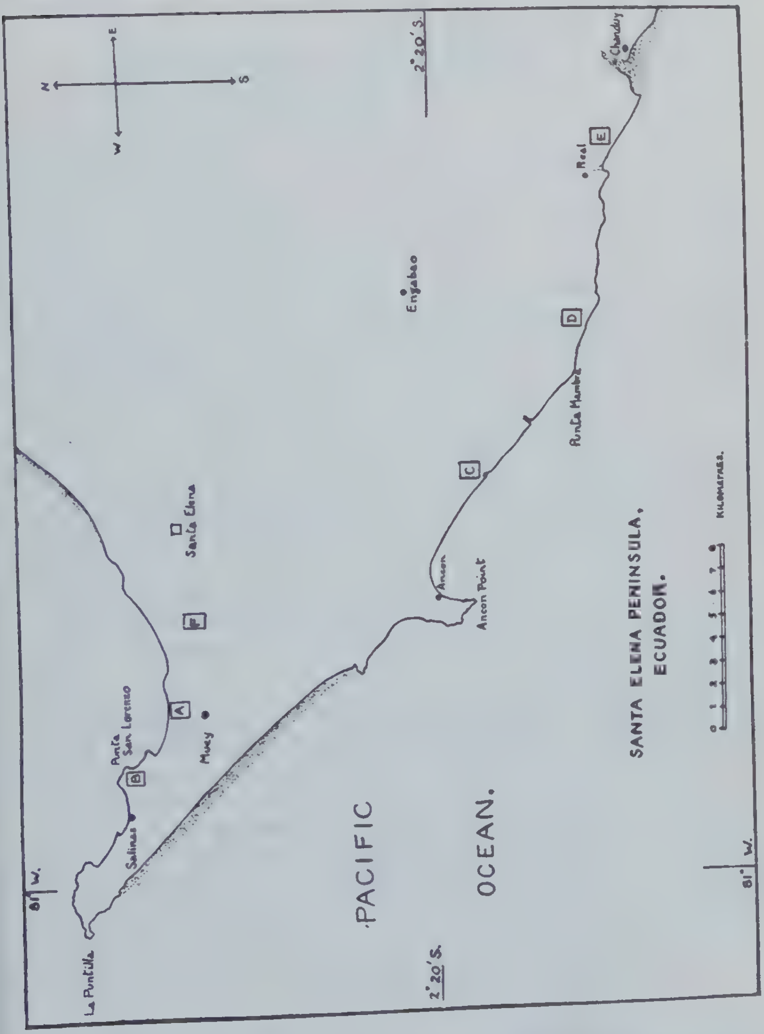

FIG. 1.—Sketch-map showing localities (A)–(F).

The mollusca show considerable differences in condition according to the formation containing them. Those in the sandier beds are usually preserved as casts, all aragonite material having been leached out, but those in the more calcareous beds are usually well preserved, in some cases retaining much of their original colouring. The Ostreas and Pectens are exceptions in the sandier beds, their calcite shells successfully resisting solution.

As a whole, the Ecuadorian fauna is very similar to that recorded from the Tablazos of north-west Peru, as might be expected from a general similarity in existing conditions, the Panamic Province of conchologists extending from the Gulf of California to Paita in Peru. Identical fossil species in the two areas include *Cerithium adustum*, *Arca grandis*, and the large species of *Ostrea* which gives rise to widespread and characteristic " Oyster Beds ". A large species of *Conus*, comparable to *C. fergusoni* and *Balanus tintinnabulum* var. *concinnum* Darwin are also common in some localities, particularly in the neighbourhood of Punta Mambra. Further similarity between north-west Peru and south-west Ecuador is to be found in the local nature of faunal groups, resulting in " Echinoid Beds ", " Gastropod Beds ", or the " Oyster Beds " mentioned.

SHORT NOTES ON LOCALITIES A–F. (See Fig. 1.)

(A) *Muey Tablazo.*

The beds here are level-bedded sands with very little cementing material, containing narrow bands made up almost entirely of a large scuttellid echinoid (*Encope micropora* L. Ag.) and a large thick-shelled lamellibranch (*Spisula* sp.). The fossils all lie along the bedding, and retain much of their original colouring. The intervening layers, however, are of practically barren sand.

(B) *Punta San Lorenzo.*

The beds are for the most part well-cemented calcareous sandstones with a rich and varied molluscan fauna. The following species were collected :—

Bullaria aspersa (A. Adams).
Columbella strombiformis Lamarck.
Trivia sanguinea Gray.
Trivia radians Lamarck.
Cerithium adustum Kiener.
Cerithium sp.
Turbo magnificus Jonas.
Uvanilla unguis (Wood).
Natica sp.
Mytilus sp.

(C) *Near the Mouth of Quebrada Seca.*

The Tablazo exposed here is a chalky limestone of a yellowish colour, very soft, and crumbling readily to a fine dust. The fossils collected from it were not very numerous and were all lamellibranchs, suggesting that the shells were not drifted but in situ, the deposit having been a bank of chalky mud. The shells were slightly decalcified and entirely decolorized. The following species were recognized :—

Arca (*Anadara*) *grandis* Broderip and Sowerby.
Anomalocardia subrugosa (Sowerby).
Glycimeris inaequalis (Sowerby).
Pecten sp. (fragments only).

(D) *On the Coast between Punta Mambra and Rio Real.*

The succession is very varied, some of the beds being rich in fossils and others quite barren; a detailed account has been published by Dr. Sheppard ((6), 498–9).

A "gastropod bed" about 2 feet in thickness and composed very largely of casts contained *Conus* sp., *Strombus* sp., *Natica* sp., and numerous specimens of a large *Turritella* which attained a length of nearly 6 inches (cf. *Turritella goniostoma* Valenciennes). A few Pectens with well-preserved shells and numerous specimens of *Ostrea* sp. were obtained from the same bed. A short distance to the south a limestone band was examined, and a large *Cypraea* (*C. exanthema* Linnaeus) and several specimens of *Oliva* (*O. angulata* Lamarck) were obtained, the shells being in excellent condition and retaining much of their original colouring. A number of specimens of *Anomalocardia*, *Chione*, *Pecten*, and *Ostrea* were also collected.

The surface beds along this portion of the coast are of a fine-grained loess-like nature with numbers of excellently preserved land shells. These have been assigned to the species *Porphyrobaphe iostoma* (Sowerby) and *Lissoacme bilineata* (Sowerby). The latter is unimportant, being found throughout the Peninsula, but the former is of considerable interest. At the present time it is found living in the neighbourhood north of Colonche, where there is more moisture than further to the south. Here it occurs in enormous numbers during the wet season from January to April. It may be that it spread to the coastal area, some 50 odd miles to the south of its present habitat, during an exceptionally wet period, or possibly the area possessed a damper climate when the Tablazo was deposited. In either case a former period of greater precipitation is indicated by the surface bed near Punta Mambra.

(E) *Near the Mouth of Rio Real.*

The beds are principally shell-beds separated by thin lenses of chalky limestone and occasionally by current-bedded calcareous sands. The shell-beds contain a rich molluscan fauna very similar to that obtainable from the present beach in the same locality.

Several echinoids were collected including *Arbacia incisa,* which also occurs in Pliocene Silts to the north of Canta Gallo, and in large numbers, living, in Santa Elena Bay. Amongst the more numerous fossils collected were :—

Conus fergusoni Sowerby.
Oliva angulata Lamarck.
Cerithium adustum Kiener.
Uvanilla unguis (Wood).
Anomalocardia subrugosa (Sowerby).

Balanus tintinnabulum var. *concinnum* Darwin was extremely common, and a single specimen of *Coronula diadema* (Linn.) was obtained.

(F) *Brea Pits between Santa Elena and Muey.*

Between Santa Elena and Muey are extensive deposits of Brea, or viscous mineral tar, which were exploited for oil in the early days of the Spanish conquest (Sheppard (3)). In these deposits, as in similar beds in California, large numbers of mammalian remains are to be found. It was from here that Wolf obtained *Mastodon andium* and *Equus andium* (*vide ante*). Similar remains have been observed in fluviatile sands exposed in the almost perpendicular cliffs bordering several of the dry valleys which traverse the peninsula, but no collecting has been done.

COMPLETE LIST OF SPECIES COLLECTED.

GASTROPODA.

(*a*) *Marine Gastropoda.*

Bullaria aspersa (A. Adams)	B.
Conus fergusoni Sowerby	D, E.
Oliva angulata Lamarck	D, E.
Columbella strombiformis Lamarck	B.
Phyllonotus radix (Lamarck)	E.
Acanthina muricata (Broderip)	E.
Cypraea exanthema Linnaeus	D.
Trivia radians (Lamarck)	B, E.
Trivia sanguinea Gray	B.
Strombus granulatus Gray	D, E.
Cerithium adustum Kiener	B, E.
Cerithium sp.	B.
Turritella goniostoma Valenciennes	(? D), E.
Natica sp.	B, D.
Turbo magnificus Jonas	B.
Astraea (*Uvanilla*) *buschii* (Philippi)	E.
Uvanilla unguis (Wood)	B.
Fissurella virescens Sowerby	B, E.

(*b*) *Pulmonata.*

Porphyrobaphe iostoma (Sowerby)	D.
Lissoacme bilineata (Sowerby)	D.

PELECYPODA.

Arca (Anadara) grandis Broderip and Sowerby	C, E.
Glycimeris sp.	C, E.
Glycimeris inaequalis (Sowerby)	C, D, E.
Ostrea cf. *chilensis* Philippi	D.
Pecten ventricosus Sowerby	D.
Spondylus cf. *crassisquama* Lamarck	E.
Cytherea multicostata Sowerby	A.
Chione guidia (Broderip and Sowerby	E.
Anomalocardia subrugosa (Sowerby)	C, D, E.
Semele flavescens (Gould)	A.
Spisula sp.	A.
Mytilus sp.	B.

CIRRIPEDIA.

Balanus tintinnabulum (Linn.) var. *concinnum* Darwin	D, E.
Coronula diadema (Linnaeus)	E.

ECHINOIDEA.

Encope micropora L. Agassiz	A.
Arbacia incisa (A. Agassiz)	E.

While this paper was in the press the following species from locality (B) have been identified by Mr. J. R. le B. Tomlin, to whom the author wishes to express his thanks :—

Seminella nigricans (Sowerby).
Trivia pacifica Gray.
Hipponyx barbata Sowerby.
Callopoma saxosum (Wood).
Tegula sp. cf. *cooksoni* Smith.

SUMMARY AND CONCLUSION.

The shell-beds, as has been pointed out, show great similarity to those of Peru. Corals are few in number, being more plentiful to the north in the neighbourhood of Punta Ayangue, and the Coral Mounds which Bosworth describes as plentiful in the Peruvian Tablazo appear to be absent. In general, many of the beds are similar in lithology to the various " Crags " and " Faluns " of European Tertiaries, but lateral and vertical variation is much more marked than in them probably owing to the accumulation taking place not far from shore on a coast subject to the powerful currents of the Pacific Ocean.

The deposits as a whole provide an excellent example of the modern " Facies " doctrine, and the grouping of faunal assemblages in different localities may well be attributed to local changes in conditions of sedimentation.

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The "Incised Meanders" near Pont-erwyd, Cardiganshire.

By John Challinor, M.A., F.G.S., University College of Wales, Aberystwyth.

In the neighbourhood of Pont-erwyd and Devil's Bridge in North Cardiganshire, the Afon Rheidol flows through a series of gorges; and it seems probable that these have not all of them the same history.

Below Pont-erwyd there are two gorges with some remarkable features, and these form the subject of this note. Neither is on a large scale, but each is strongly characterized in having precipitous sides and a loop-shaped plan. One of these is well known as a "typical incised meander", but it is here suggested that both of them are due, not to the rejuvenation of an already meandering stream, but to a glacial accident: the choking by boulder-clay of a rather steep-sided channel (probably somewhat "entrenched") and the diversion of the river at two points from a comparatively straight, into a very sinuous, course; with the production of additional, sharply cut, post-glacial channels.[1]

The first, and most obvious, case of glacial obstruction with consequent diversion, is plainly visible from the high road at the village. South of the bridge the river flows for about 200 yards in a south-south-easterly direction and then, fronted by a bank of boulder-clay, turns sharply back upon itself and plunges down a few small waterfalls into a gorge with almost vertical sides. Through this gorge the river makes a detour, regaining what appears to be the original pre-glacial channel about 150 yards south of the point where it left it.

A striking and peculiar feature is the position of the gorge on the side of a slope, and the rise of the top of the gorge as it is followed downstream from the point of diversion. It looks as if the choking and diverting mass of boulder-clay were originally much higher

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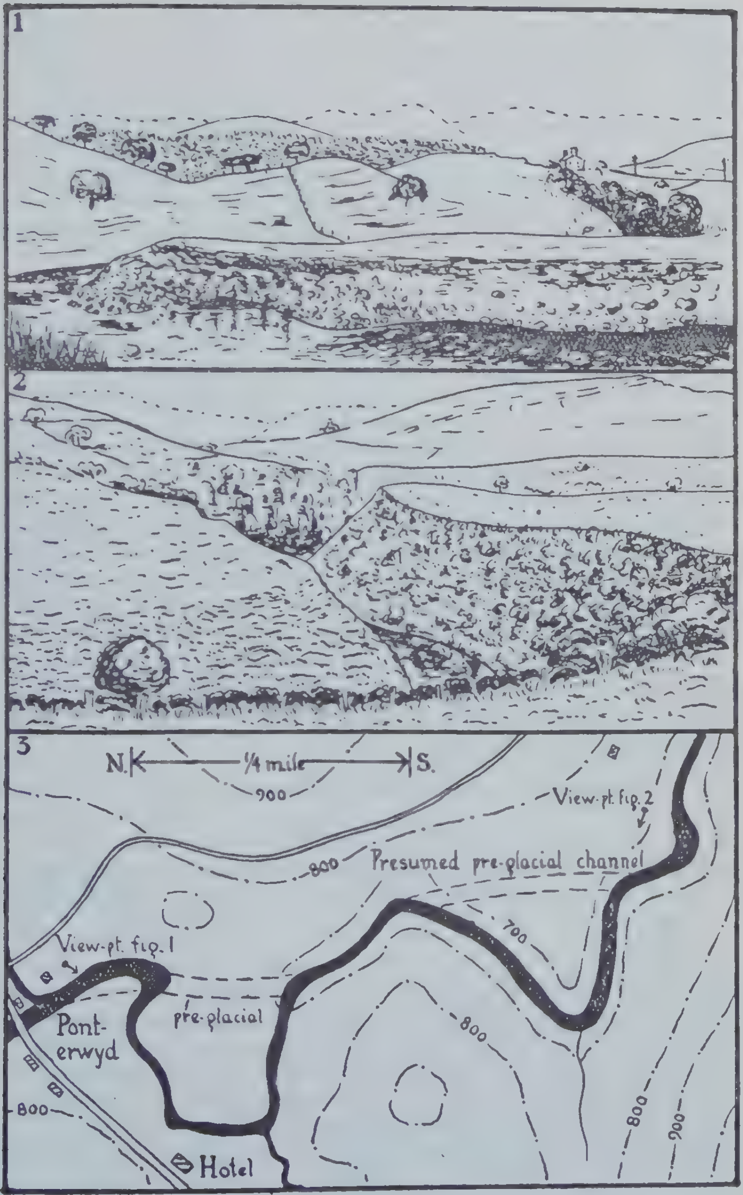
[1] Compare the post-glacial diversions of the Dee (L. J. Wills, *Quart. Jour. Geol. Soc.*, lxviii, 1912, 180), and those in Caithness (C. B. Crampton, *Mem. Geol. Surv.*, 1914, 152).



FIGS. 1–3.—Sketch-views and a sketch-map of the “ incised meanders ” near Pont-erwyd, Cardiganshire.

than it is to-day, so that the top of the present gorge at its highest point was the lowest point of escape of the water, which was presumably to some extent ponded behind. Probably the ice itself played a part in the diversion. At first the river would fall steeply where it rejoined the original channel, and the gorge would no doubt be carved by a retreating waterfall that diminished in height as it retreated, the land through which it was cutting becoming lower upstream. The Llywernog stream cascades into this newly-cut incised loop and thus hangs conspicuously.[1]

In *Wild Wales* Borrow gives a graphic description of this "awful chasm".

Continuing to follow the river downstream we find that, on emerging into its original channel, it flows south-eastwards along a less sinuous course in a steep-sided, but not precipitous valley; and the banks are altogether in "solid" rock. After about 300 yards boulder-clay is seen at a broad bend, and the river appears again to have been diverted to form another incised loop; though the evidence here is by no means conclusive. This is the "incised meander" of which the photograph [2] has been used to illustrate an effect of rejuvenation; it has even reached an American textbook. But if the origin here suggested be correct, rejuvenation has played no essential part in its formation. The boulder-clay, which on the present view is supposed to be filling a pre-glacial channel, has not here been worn into a hollow, as it has just below Pont-erwyd; but the top of the gorge is not exactly in the lowest part of the valley in which it has been carved. The loop is not in this case so pronounced in form as in the case of the gorge first described; neither is this gorge quite so sharply cut nor has it quite such precipitous sides.

REVIEWS.

THE GEOLOGY OF THE CHEVIOT HILLS. By R. G. CARRUTHERS, G. A. BURNETT, and W. ANDERSON. Expl. sheets 3 and 5 Mem. Geol. Survey. pp. v + 174, with vii plates and 2 figures. 1932. Price, 4*s*.

FOR petrologists, the Cheviots have long been a classical region, owing to the important conclusions as to the possibility of the differentiation of igneous magmas that arose from Teall's study of the dykes during the 'eighties of last century, soon supplemented by Harker and Marr at Shap. It now appears that the distribution of the dykes was not so radial as Clough and Teall supposed: it is rather referred by the present authors to two swarms, more or less Charnoid and Caledonoid in direction. This is, of course, only natural if we take into account the grain of the deep-seated rocks that must underlie this or any other area in North England or South Scotland. It is not surprising to hear that the augite-granite is more or less of a myth, the pyroxene-bearing portions, which are not extensive, being attributed to contamination. The granite is mainly granophyric, with microperthite, not very abundant biotite, and a little tourmaline. There is every variety between this and the basified varieties, according to the amount of assimilation.

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[1] This fall is shown on the photograph of the Geological Survey, No. A 387.

[2] Geological Survey collection, No. A 389.

An interesting account is given of the glacial deposits, with many marginal channels, but the solid non-igneous geology does not call for any particular comment.

ERGEBNISSE GEOLOGISCHER FORSCHUNGEN IN MINAS GERAES (BRASILIEN). By B. VON FREYBERG. pp. 401, with xvii plates, 53 figures, and 2 coloured maps. Stuttgart: Schweizerbart, 1932. Price RM 52.

THIS is an exasperating book. Everybody with any acquaintance with economic geology knows that the State of Minas Geraes is of great interest as a mining region, as indeed its name implies. Hence the title raises hopes of information of an up-to-date character on this aspect of its geology. It is true that some space is devoted to an account of the Itabirite formation and its iron ores, but the gold-mining of Passagem seems to be dismissed in two lines. Furthermore the reviewer has been unable to discover any mention whatever of the Morro Velho (St. John del Rey) mine, which is of extraordinary interest, and one of the deepest in the world (over 7,000 feet vertical or 10,000 feet down the dip). This failure may be due to the absence of any general index. There is a very large bibliography, arranged chronologically, and this *has* an index of its own, of authors' names, but it is impossible to find a reference to any particular locality.

Finally, a book of 400 pages issued at RM 52, about £3 15*s*. at present exchange, ought not to fall to pieces the first time anybody tries to read it.

INTRODUCTION TO THE SCIENTIFIC SIDE OF THE SOIL. By N. M. COMBER. Second edition. Edward Arnold & Co., 1932.

THE original edition of Professor Comber's book appeared at a time when soil workers had developed a new viewpoint. He was the first to produce a student's textbook embodying the result of recent research and emphasizing the changed outlook of pedologists. The volume supplied the needs of teachers and students, and Professor Comber may be congratulated on the fact that comparatively little rewriting was required for the second edition (1932), in spite of the many recent soil research papers. The new edition presents the salient facts of the subject in a clear and interesting manner, and the book will continue to be a valuable aid to the elementary student. A useful feature of the volume is a short chapter on the reaction of aqueous solutions, which might with advantage have been extended to more detail, as the agricultural student frequently finds a difficulty in understanding the fundamentals of the theory of that important branch of the subject, and the chapter on soil particles might also have been enlarged in view of the importance of this branch of soil analysis. But within the space of some 203 pages, Professor Comber has dealt with all the more important aspects of the subject in an adequate and interesting manner.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

1st November, Anniversary Meeting.

Professor H. H. Read and Mr. B. E. Dixon: "On stichtite from Cunningsburgh, Shetland."

Stichtite is found at the above locality as rose-pink patches, partly replacing chromite in a serpentine-rock. Characters determined include D = 2·19, refractive indices γ 1·559, α 1·543. Probably biaxial. Chemical analysis and discussion of earlier analyses give as the most probable formula—

$$2(Cr,Fe)(OH)_3.5Mg(OH)_2.MgCO_3.Mg[CO_3.(OH)_2].4H_2O.$$

Professor H. H. Read: "On quartz-kyanite rocks from Unst, Shetland Islands, and their bearing on metamorphic differentiation."

Quartz-kyanite rocks occur as veinlike bodies in kyanite-chloritoid-schist, also as blocks scattered over the slopes. They are intimately associated with rocks much poorer in silica and richer in alumina than the normal country rock. The main component of these associated rocks is kyanite, with chlorite, and iron "ore". The origin of the rocks and certain general problems connected with metamorphic differentiation are discussed.

Dr. L. J. Spencer: "A new meteoric iron found near Kyancutta, South Australia."

A mass of iron weighing 72 lb. was found in June, 1932, just below the surface in a sandy paddock, 28 miles E.S.E. of Kyancutta. It shows the characters of the common type of medium octahedrites, and is very similar to the numerous masses of iron found around the meteorite craters near Henbury, in Central Australia, 630 miles distant from Kyancutta.

Mr. C. A. Silberrad: "List of Indian meteorites."

The places of fall of the 106 meteorites that have been recorded in India since 1795 are located as accurately as now possible, and plotted on a map. Percentages are given for the day and night falls and of the monthly falls.

Mr. W. Campbell Smith: "Meteoric stones from Suwahib, Arabia."

Within 30 miles of Buwah in Suwahib, where Mr. Bertram Thomas found a chondritic meteoric stone in 1931, two other stones were found a year later by Mr. Philby. They closely resemble the Buwah stone and may belong to the same shower. Sixty miles to the south a third stone was found at Umm Tina, near Shanna well. This is a chondrite of Baroti type and differs from the other two, which belong to the Cronstad type.

Mr. Arthur Russell: "An account of British Mineral collectors and dealers in the seventeenth, eighteenth, and nineteenth centuries (continued)."

Sir Charles Lewis Giesecke, K.D. Born 6th April, 1761, died 5th March, 1833, was christened Johann Georg Metzler. Wrote the libretto of Mozart's "Magic Flute" (1791), also other operas. In 1794 he began the serious study of mineralogy and travelled extensively. Later he settled in Copenhagen. In 1806 he undertook a mineral collecting trip to Greenland and remained there seven years, amassing a large collection. The specimens collected during the first two years were captured by an English frigate on their way to Denmark, and were brought to Leith, where they were bought by Thomas Allan. On his return from Greenland in 1813, Giesecke landed at Leith and traced his collection to Allan, with whom he became very friendly. In 1814 he was appointed Professor of Mineralogy to the Royal Dublin Society, which position he held until his death.

Mr. Arthur Russell: "Note on an occurrence of witherite at the Morrison North Pit, Stanley, co. Durham."

Pure, massive witherite fills a fault-fissure cutting coal at this pit.

Mr. M. H. Hey and Mr. F. A. Bannister: "Studies on the Zeolites, Part IV. Ashcroftine (Kalithomsonite of S. G. Gordon)."

The pink zeolitic mineral described by S. G. Gordon in 1924 as a potassiferous thomsonite (kalithomsonite) is shown by X-ray and optical data to be an independent species in no way related to thomsonite, and the name ashcroftine is proposed for it. Ashcroftine is tetragonal with cell-sides c 17·49, a 34·04A., a unit-cell content about $40[NaK(Ca,Mg,Mn)Al_4Si_5O_{18}.8H_2O]$, and D 2·61 ± 0·05. The refractive indices (ϵ 1·545, ω 1·536) are much higher than those of artificial potassiferous thomsonites, and the optical orientation is different.

Miss W. C. A. Guthrie and Dr. Christina C. Miller: "The determination of rock constituents by semi-micro-methods."

The ordinary course of the analysis of an igneous rock can be very considerably expedited by the use of smaller amounts of material throughout, the necessary accuracy of weighing being attained by means of a microbalance. Numerous experiments show that such a procedure is reliable and involves no loss of accuracy.

CORRESPONDENCE.

COAL MEASURE FLORAS.

SIR,—I beg to place on record the results to date of an investigation of the plant horizons occurring in the Clackmannan and Fife Coalfields. Previous records from these areas, on the authority of Dr. Kidston [1] have hitherto been assigned to his Lanarkian Series.

On the basis of the plant assemblages characteristic of the Yorkian and Lanarkian Series, as revised by Dr. Crookall [2] the measures above the Coalsnaughton Main in the Clackmannan area contain a major proportion of Yorkian species.

The general barrenness of the Mid-Cherry and the Coalsnaughton Main, together with the occurrence of *Neuropteris rectinervis* Kidst. in the Coalsnaughton Main and in an ironstone rib, which is 5 feet above the seam and 3 feet above a mussel-band with *Carbonicola pseudorobusta* Trueman, would appear to indicate that these two seams at least come within Kidston's "Lanarkian" Series.

This reading of the sequence is in close agreement with the results obtained by Dr. Crookall [3] in the Stirlingshire area, where the top of the Lanarkian has been placed at approximately the level of the Auchingane Coal, correlated by Dr. Murray Macgregor [4] with the Mid-Cherry.

With regard to Fife, *Neuropteris rectinervis* Kidst. has been obtained from a bed 12 feet below the *Carbonicola pseudorobusta* Trueman mussel-band in Gallatown Quarry, Kirkcaldy, a horizon which is approximately 100 feet above the Dysart Main. As in Clackmannan, the higher seams have yielded a majority of Yorkian species and, since there is little doubt that the Dysart Main is roughly the equivalent of the Coalsnaughton Main of Clackmannan and the Mid-Cherry of Stirlingshire, we now have a general agreement between these three eastern coalfields.

The work is being continued with the aid of a grant from the Government Grant Committee of the Royal Society, and a detailed description of the evidence obtained will be published shortly.

R. GREGORY ABSALOM.

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NATURAL HISTORY DEPARTMENT,
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GLASGOW.

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